PIONEERS OF WIRELESS

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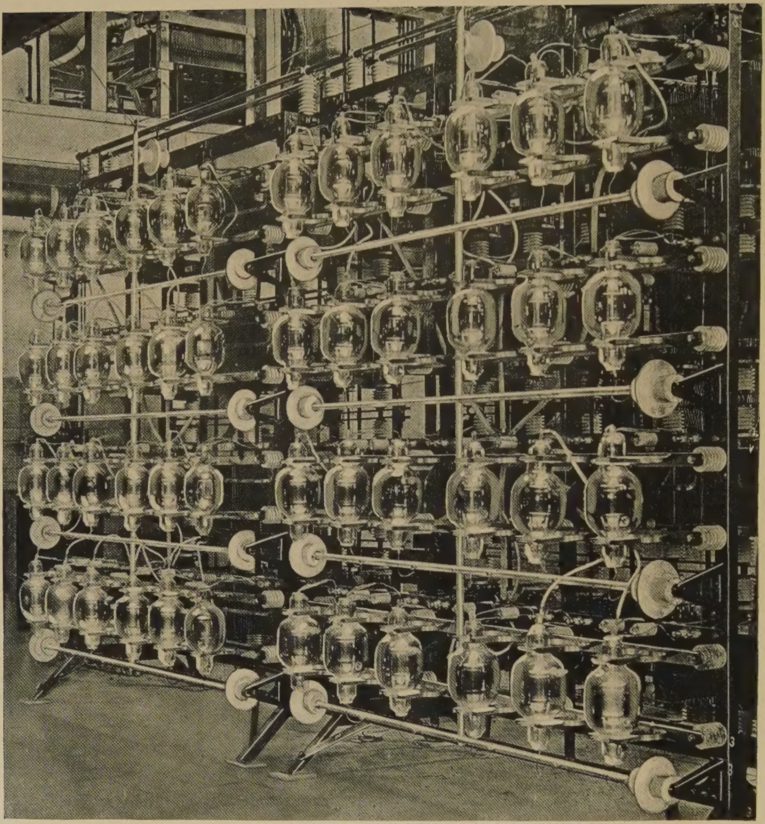

THE LARGEST VALVE PANEL IN THE WORLD

BANK OF 48 TRANSMITTING VALVES AT THE MARCONI STATION, CARNARVON

17034

PIONEERS OF WIRELESS

BY

ELLISON HAWKS
F.R.A.S.

WITH 24 PLATES AND 45 DIAGRAMS

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PREFACE

"RARELY does it happen that any discovery or invention of importance is made by one man alone", wrote diligent Samuel Smiles. "The threads of inquiry are taken up and traced, one labourer succeeding another, each tracing it a little further, often without apparent result. This goes on sometimes for centuries, until at length some man, greater perhaps than his fellows, seeking to fulfil the needs of his time, gathers the various threads together, treasures up the gain of past successes and failures, and uses them as the means for some solid achievement." Wireless is an outstanding example of the truth of this, for the work of the pioneers was gathered together by Marconi, to achieve results that fill the needs of his time.

The transmission of intelligence by means of preconcerted signals has been practised from the most ancient times, the use of beacons by night and columns of smoke by day for this purpose being referred to in the Bible. Among the savage nations, drums have long been, and are still, used to transmit messages over wide areas, in some cases with remarkable speed. In 1910 an explorer, T. C. Taylor, who was in the heart of Africa and 200 miles from the nearest telegraph line, learned the result of the Jeffries-Johnson fight within 12 hours of the contest. The news had been telegraphed to a port on the coast and quickly spread over the town. On the hills was a native who beat out the news on a drum, a "listener" on a neighbouring hill repeated it, and so the news was successively taken up and passed along by a chain of drums until it had crossed hundreds of miles of jungle.

Fire, smoke, drums, and similar devices for the transmission of intelligence were later supplemented by mechanical contrivances, one of the earliest of which was invented by Claude Chappe, who, in 1793, used a wooden beam rotating on a centre post to communicate over a distance of a mile and a half. This system was later adopted by the French Government, who established stations throughout France. In England, lines of semaphore telegraphs were first established in 1795 between the Admiralty and Dover. They worked at a comparatively high rate of speed, it being possible to transmit a message from London to Dover in 10 minutes, the message being relayed from point to point. This speed was exceeded in the semaphore telegraph established in 1826 by the trustees of the Liverpool Docks, between Liverpool and Holyhead. There were 11 stations within sight of each other and placed at an average distance of a little less than eight miles apart. The semaphores were set on heights and commanded the whole line of coast and seaboard from Liverpool to Holyhead. On one occasion a question was sent along the line to Holyhead and the answer was received back at Liverpool in 23 seconds. Such mechanical devices as these were replaced by the electric telegraph, which in more recent years has been augmented by wireless.

In these pages an attempt has been made to outline the development of wireless telegraphy more particularly from the point of view of the early workers, in the hope that some of the pioneer work may be recovered from the past and accorded a permanent record. It is due to those pioneers of wireless, who devoted so much time and thought to the prosecution of their experiments, that they should be awarded some share of the honour that has fallen to those who, in recent years, have built on their early discoveries. The work of Hughes and Dolbear—both of whom succeeded in transmitting signals by wireless—is too often relegated to the " limbo of the past " and is overshadowed by the more outstanding achievements of Clerk-Maxwell, Hertz, Branly, Lodge, and Marconi.

One cannot read of the discoveries of the pioneers of wireless without noticing how many of these discoveries were made by men who originally had no direct connection with electrical science. Dr. Gilbert of Colchester, the first to investigate the magnet, was physician to Queen Elizabeth. Benjamin Franklin, who established the identity between electricity and lightning, was a printer and later a politician. Thomas Young, the protagonist of the undulatory theory of light, was a doctor. Sturgeon, the inventor of the electro-magnet, was a soldier and carried out his earlier experiments within the walls of a barracks. Morse was a painter and sculptor. Alexander Graham Bell, the inventor of the telephone, was a teacher of deaf-mutes. David Hughes, inventor of the microphone, was a professor of music.

As the title of this book implies that it deals with " those who go before to prepare the way for another ", it should, strictly speaking, end with the consideration of those whose work dated prior to the time of Marconi. At the same time, it is realized that the story would be regarded as incomplete without some account of Marconi's pioneer work. Similarly, it was thought desirable to include a short account of the Thermionic

Valve—of which Fleming must be regarded as being the pioneer—and a brief reference regarding the development of wireless telephony. The more recent, and very extensive, subject of television has not been dealt with in the present volume, however, it being regarded as but in an embryo stage, for at the time of writing much remains to be done in this field.

Necessarily, in a book that is limited in space only the more prominent pioneers can be dealt with, and in particular does this limitation refer to the work done in more recent years. For this reason the names of many workers have necessarily to be omitted. The most outstanding instance, perhaps, is that of General Ferrié, whose splendid work during the war in connection with wireless for the French Army is so well known.

The writing of a book such as this is no easy task, and although every precaution has been taken to make it as accurate as possible, there are, no doubt, some errors. It is hoped that readers discovering any mistakes will be good enough to point them out, so that they may be corrected in future editions. I should like to add that I have endeavoured to be as fair as possible to all pioneers dealt with, and I hope I have done no injustice to any. At all times I shall welcome any additional information regarding the work described, or information of additional pioneer work that has not hitherto been made public, for inclusion in future editions of this book. May I apply the remarks with which Sir Isaac Newton closed the Preface to his immortal *Principia*, when he said: " I earnestly entreat that all may be read with candour, and that my labours may be examined not so much with a view to censure but to supply their defects ".

In conclusion, I must acknowledge my indebtedness to various sources for assistance willingly given. So far as concerns the numerous works consulted, reference is made to the more important authorities by footnotes. I desire specially to mention the usefulness of two books by J. J. Fahie: *A History of Electric Telegraphy to the Year 1837* and *A History of Wireless Telegraphy from 1838 to 1899.* From them I have drawn much information in regard to the earlier forms of telegraphy and suggestions for wireless telegraphs.

In regard to the illustrations, the collection of a complete series of portraits from many and world-wide sources has been a lengthy task. My thanks are due to the Head Master of Cheltenham College for permission to reproduce the portrait of Henry Highton and to Mr. A. H. Preece for permission to use the photograph of his late father. For permission to reproduce photographs of the early wireless apparatus I have also to thank Marconi's Wireless Telegraph Co., Ltd., and the Director of the Science Museum, South Kensington. Mr. G. R. Heaviside and Mr. J. S. Wilkins have kindly supplied information regarding the pioneer work of their relatives, and I am indebted to Mr. W. H. McCormick for kindly reading through the proofs.

ELLISON HAWKS

"ARCETRI,"
DUDLOW LANE, LIVERPOOL

October 1927

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SOME NOTABLE DATES IN THE HISTORY OF WIRELESS

B.C.	
2600	Magnet used as compass by Chinese
1000	Greeks obtain lodestone from Magnesia
A.D.	
1600	Gilbert investigates magnetism and publishes *De Magnete*
1671	Otto Guericke invents first electrical machine
1724	Stephen Gray discovers principles of conduction and insulation
1742	Gordon improves the electrical machine
1745	Invention of Leyden jar
1746	Winkler discovers earth return
1748	Watson concludes electricity travels instantaneously
1752	Franklin identifies lightning and electricity
1780	Galvani discovers current electricity
1796	Volta discovers contact electricity and evolves the voltaic battery
1811	Sömmering uses water to conduct current for his telegraph
1820	Oersted shows connection between electricity and magnetism
	Schweigger makes possible the construction of instruments for measuring currents
1820	Ampère invents astatic needle
1825	Sturgeon discovers electro-magnet
1828	Henry improves electro-magnet
1831	Faraday discovers magneto electricity
1832	Henry discovers induction. Morse invents his code
1838	Steinheil suggests the use of "earth return"
1842	Morse signals without wires by conduction
1849	Wilkins suggests signalling by induction between England and France
1850	Guitard notices coherence of dust particles
1854	Lindsay patents his plan for communication by conduction
1864	Clerk-Maxwell predicts existence of electro-magnetic waves
1866	S. A. Varley uses coherence for lightning protector
1876	Bell invents the microphone
1879	Hughes experiments with, and discovers, Hertzian waves
1880	First wireless telephone Bell's photophone
1882	Dolbear applies for patent for his system of wireless telegraphy
1882	Preece signals by conduction across the Solent
1883	Lodge re-discovers principle of cohesion
1884	Trowbridge suggests signalling by induction to ships at sea
1885	Edison signals to trains in motion by induction
1886	Dolbear sends wireless signals over 13 miles

A.D.	
1887	Preece signals by induction to coal-mine
1888	Hertz discovers electro-magnetic waves
1891	Branly introduces the coherer
1892	Preece signals over five miles in the British Channel
1895	Communication maintained by Preece's method between Isle of Mull and Oban (two miles) on breakdown of cable
1895	Popoff introduces the electric "tapper-back" in conjunction with Branly's coherer
	Marconi makes his first experiments in Italy
1896	Marconi comes to England and transmits over increasing distances
1897	Righi improves Hertz's transmitter
	Lodge patents his system of tuning
1898	Preece's system of wireless permanently established between Lavernock and Flat Holm and handed over to War Office
1898	Call-bell added to Preece's installation
1899	Preece telephones without wires between Rathlin Island and the mainland (eight miles)
	Marconi signals across the Channel
1900	Marconi system adopted by Norddeutscher Lloyd Steamship Co. British Admiralty contract for the equipment of 26 warships with Marconi apparatus. Marconi's famous "four sevens" (No. 7777) master patent regarding tuning
	Duddell invents arc transmission
1901	Marconi bridges the Atlantic
1902	Marconi invents the magnetic detector
1903	Poulsen patents continuous-wave system, based on Duddell's arc.
	Commencement of regular wireless service to ships at sea
1904	Fleming patents the "oscillation valve"
1905	Marconi uses directive aerial. Erection of first high-power station commenced at Clifden
1906	Dunworthy and Pickard introduce crystal detectors
	Max Wien suggests quenched spark-gap
1907	De Forest patents the triode and revolutionizes wireless signalling
	Commercial transatlantic service opened between Clifden and Glace Bay
1910	The G.P.O. takes over Marconi coast stations
1911	Goldschmidt uses high-speed alternator
1915	First wireless telephone messages from Arlington (U.S.A.) to Paris. Wireless speech first received from an aeroplane
1920	Melba sings for successful demonstration of broadcasting from Chelmsford
1921	Directive short-wave wireless telephone transmission from Hendon to Birmingham

SOME NOTABLE PIONEERS OF WIRELESS

AMERICA

Alexanderson
Armstrong
Bell
De Forest
Dolbear
Dunwoody
Edison
Fessenden
Franklin
Goldschmidt
Henry
Langmuir
Loomis
Morse
Pickard
Tainter
Tesla
Trowbridge
Watson

AUSTRIA

Gintl
Sacher

BRITAIN

Bevis
Brown
Clerk-Maxwell
Davy
Dering
Duddell
Faraday
Fleming
Gilbert
Gordon
Gray
Haworth
Highton, E.
Highton, H.
Hughes
Johnston
Lindsay
Lodge
Melhuish
Muirhead
O'Shaughnessy
Preece
Sturgeon
Varley
Watson
Wilkins
Willoughby Smith

DENMARK

Oersted
Poulsen

FRANCE

Ampère
Arago
Bouchotte
Bourbouze
Branly
Douat
Ferrié

GERMANY

Goldschmidt
Guericke
Hertz
Schilling
Slaby
Sömmering
Steinheil
Wien
Winkler

HOLLAND

Musschenbröck
Von Kleist

ITALY

Bellini
Bonelli
Calzecchi-Onesti
Galvani
Marconi
Righi
Tosi
Volta

RUSSIA

Popoff

SPAIN

Salva

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PIONEERS OF WIRELESS

CHAPTER I

WILLIAM GILBERT, FAMOUS ELIZABETHAN, INVESTIGATES MAGNETISM; THE DISCOVERY OF THE LEYDEN JAR; BENJAMIN FRANKLIN AND HIS EXPERIMENT WITH A KITE

THE story of the invention and development of a practical system of communication without wires is one of the most remarkable in the annals of science. Wireless as we know it to-day is not the outcome of the work of any one man, as is sometimes erroneously stated, but is the result of the labours of a large number of pioneers, whose researches, made with a definite object in view, extend over the past century. Then, too, credit must also be given to even earlier workers, whose all-important investigations, conducted during the past three or four hundred years, enabled the science of Electricity and Magnetism to be placed on a sound basis upon which later workers were able to build with safety. It is the work of all these men that has led to the amazing discoveries of the twentieth century.

There is no better method of following the progress of any science than that of studying the lives of the pioneers who marked out the trail across unknown land. In any stage play the characters make the show, and the scenery and setting would be useless without the human element. So it is with the story of any science—and more particularly so, perhaps, with wireless—and by studying the lives of the early workers we are better able to appreciate how this great science has been built up. The knowledge thus gained helps us to realize the vast amount of labour and research that has been necessary to reach the present state of our advancement. It also helps us to understand exactly what radio means, and to realize the great physical laws and the vast significance and wonder that lie behind even the faintest "click" of a Morse "dot" or "dash" heard in our receiver.

Although great and rapid strides have been made during the past five or six years, the discovery of the possibility of wireless transmission and reception has been a gradual evolution. It was more especially the result of the combined efforts of many eager minds, who for a hundred years had been striving to grasp the prize. Success was only made possible by persistent and thoughtful study, by the conquest of difficulties, and by overcoming obstacles that were at first regarded as insurmountable.

Attention to detail, and more particularly patience and perseverance, were the important qualifications of these early workers. Fortune has not favoured any one of them with chance discoveries leading by a short cut to such brilliant achievements as radio-telephony or super-regeneration. Indeed, developments have been on lines clearly recognized in every other field of scientific achievement. Watt's invention of the separate condenser, which meant so much to the success of the steam engine, was no accident, but was the outcome of close and continuous study. It was the final step in a long journey—a step that could never have been taken had not the road that led to it been carefully and thoughtfully traversed. Bernard Palissy's discovery of the process of glazing china; Gottlieb Daimler's internal-combustion engine; the Curies' discovery of radium; the Wrights' first aeroplane—these and a hundred other instances illustrate that steady and persistent research alone results in the reward of discovery; in the right to become a benefactor to mankind, and a builder in a new science.

In these pages are outlined the researches of the pioneers of wireless and more particularly of those who laid the foundations upon which Marconi, and those who followed him, built the superstructure. Considerable research has been necessary, and from the vast amount of material examined some interesting and forgotten facts have been brought to light. The claims of such workers as S. F. B. Morse, J. B. Lindsay, A. E. Dolbear, and David Hughes deserve to have a more complete recognition than they are generally afforded. It is hoped that our readers will pay tribute to the memory of these and the other pioneers, whose work to-day is too often forgotten, misrepresented, or undervalued.

II

As everyone knows, magnetism plays an all-important part in wireless, and it is to this ancient subject that we turn for information of the earliest pioneer work. A metallic ore, possessing the peculiar property of attracting iron, was known in the remotest times and was regarded as an object of curiosity by the peoples of many nations. "The attractive power of the lodestone," says Sir John F. Davis, F.R.S., "has been known to the Chinese from remote antiquity."[1] Homer (1000 B.C.), Thales and Pythagoras (600 B.C.), Euripides and Plato (500 B.C.), Aristotle (400 B.C.), the Roman poet Lucretius, and Cicero (100 B.C.) all mention the attractive power of the magnet.[2]

The ancients also discovered the directive power of the magnet and its disposition to turn always to the north—that most wonderful property that safely guides the navigator over the expanse of oceans and makes possible the commerce of the world. Although Pliny (A.D. 100) refers to the repulsive power of the magnet, neither the Greeks nor the Romans appear to have made use of it for directive purposes. Its discovery seems to have been made in Upper Asia, and it may be that it was communicated by their Tartarian conquerors to the Chinese, who seem to have been familiar with it some considerable time before the birth of Christ. In Du Halde's *Description Géographique, Historique, etc., de l'Empire de la Chine* (published 1736), for instance, it is stated that the magnet was used "to determine the four parts of the world", at a time when the Emperor Hoangti gave battle to Tchi Yeou, about 2600 B.C. We are told that it was "by this method he overtook Tchi Yeou, made him prisoner, and put him to death". Later (about 1040 B.C.) Tchieon Kong gave certain visiting ambassadors an instrument before they returned to their own country. One side of this instrument always pointed to the north and the other to the south. "The Chinese appear to have applied the polarity of the magnet in ancient times as a guide on shore as well as at sea," says Sir John Davis. "This was effected by a machine called a 'magnetic car', in which was placed a little figure of a man, turning on a point and having its finger always directed to the same part of the horizon. . . ."[1] The first explicit notice of the common polarity of the lodestone to iron occurs in a Chinese dictionary, completed in A.D. 121.[2] The first distinct notice in Europe of the directive properties of the polarized needle appears about 1190, in a satirical poem by Guyot de Provins. They are also mentioned by Cardinal de Vitry, who visited Palestine in the fourth crusade and again at the beginning of the thirteenth century.

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[1] *The Chinese*, vol. ii, p. 223.

[2] So named by the Greeks, from Magnesia, a district in Macedonia, where it was chiefly found.

It would seem that knowledge of the directive properties of the magnet spread again gradually over the East and was introduced to Europe by the Crusaders, who between their battles had leisure to study the arts acquired by their more civilized rivals. They probably received their information from the Arabs, who were certainly using the magnetic compass about this time,[3] and they in turn no doubt derived their knowledge of it from the Chinese.

We are told that the first compasses were very rudely formed, consisting merely of a piece of the metallic ore fixed to a cork, which floated in a dish of water. An artist at Amalphi—a town on the shore of Calabria in the direct route of the Crusaders, and the then emporium of the East—improved its construction and marked the north point by a *fleur-de-lis*, the armorial bearing of the kingdom of Naples. From its directive property, the magnetic ore then became known by the English name of "lodestone", or "leading stone".

The lodestone is believed to have entered into the working of the oracles in pagan Greece and Rome. For instance, in the year 370, whilst the (Christian) Roman Emperor Valens was in power, several pagans consulted the oracle as to the destiny of the emperor and the name of his successor. The twenty-four letters of the alphabet were placed on a stool and a magician suspended a ring on a thread over the letters. The ring " moving itself and turning from one side to the other over the letters, caused them to fall upon the table and place themselves near each other, whilst the persons who were present set down the like letters in their table-books, till their answer was delivered . . . after which . . . the letters formed first of all three characters TH E O, then having added D to form THEOD the ring stopped . . . at which one of the assistants cried : ' We must not doubt any longer of it, Theodorus is the person whom the gods appoint for our emperor.' [1] Although the method of working is certainly not clear, there seems no doubt that the ring was magnetized in some way.

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[1] Sir John F. Davis, F.R.S.: *The Chinese*, vol. ii, p. 225.

[2] Ibid., p. 223.

[3] About 1242, Baylak, an Arabian writer, mentions it as being "a contrivance generally known to navigators in the Sea of Syria".

Another early reference to the subject shows that the magnet was certainly popular in the days of St. Augustine (354–430). He tells us [2] of a visit to a bishop named Severus, who held a magnetic stone under a silver plate on which a piece of iron followed exactly the movements of the hand containing the stone. He also describes how he could move a needle, placed on a floating cork, from side to side with a magnetic stone held under the table.[3]

No serious study of Magnetism seems to have been made, however, until the early part of the seventeenth century, when William Barlow (? –1625) published (in 1616) his *Magnetical Advertisements*.[4] Barlow was an eminent scientific writer who became chaplain to Prince Henry, eldest son of James I, and (in 1614) Archdeacon of Salisbury. In 1597 he published his *Navigator's Supply* and made marked improvements in the hanging of compasses at sea. He discovered the difference between iron and steel for magnetic purposes, and the correct manner of "touching" magnetic needles and of piercing and cementing lodestones. Anthony à Wood endorses Barlow's claim to have " had knowledge in the magnet twenty years before Dr. Gilbert published his book on the subject ". Wood adds that Barlow was " accounted superior, or at least equal to that doctor for a happy finder out of many rare and magnetical secrets ".

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[1] Maimbourg : *Histoire de l'Arianisme* (Paris, 1686), Webster's translation (1728), ch. vi.

[2] In his *De Civitate Dei* (written about 413).

[3] Basileae (1522), p. 718.

[4] " Magneticall Advertisements : or Divers Pertinent Observations, and approved experiments concerning the nature and properties of the Loadstone : Very pleasant for knowledge, and most needfull for practise, of travelling, or framing of Instruments fit for Travellers both by Sea and Land " . . . (London, Printed by Edward Griffin for Timothy Barlow . . . 1616).

III

It was in the reign of Elizabeth that the first serious work was done by William Gilbert, who investigated the properties of magnetism and electricity and published his famous book *De Magnete*.

William Gilbert (1540–1603), or Gilberd as he sometimes spelled his name, was the son of Hierom Gilberd, a Suffolk gentleman and Recorder of Colchester (*a*, Plate I). He was born on 24th May, 1540, at Colchester, then a fishing centre on the banks of the River Colne. Little is known of his boyhood, but at 14 years of age he entered St. John's College, Cambridge, and matriculated four years later. He was elected a Fellow on 21st March, 1561, and became examiner in mathematics. He graduated B.A. and M.A. (1564), took his degree of Doctor of Medicine (1569), and became a Senior of his College on 21st December, 1569. After spending three years in travelling through Europe to extend his knowledge, he settled in practice in London in 1573. He was elected a Fellow of the College of Physicians in 1576 and was President in 1599, and lived at St. Peter's Hill, London. Here he attained a considerable practice and in 1601 was appointed physician-in-ordinary to Queen Elizabeth, and later to James I on his accession.

Gilbert was not content to follow medicine only and regarded his profession as a means to an end. He was intensely interested in the magnet and elementary electricity and spent his limited leisure in studying these subjects. In 1600 he published his *De Magnete*, the first great physical work published in England, and his merit as an investigator was at once recognized both in England and on the Continent.

De Magnete commences with a summary of existing knowledge about the magnet and some account of the lodestone. Then follows an investigation of the properties of the magnet illustrated by diagrams and experiments ; an account of the attraction of magnets, its direction and relation to the poles of the earth, and its variation and declination. Gilbert points out the practical bearing of these points on navigation and suggests how declination may be used to discover latitude at sea. He comes to the conclusion that the phenomena of magnetism are explained by regarding the earth as a vast spherical magnet.

Though nominally a treatise on the lodestone, the book embraces the subject of electricity, and for the first time the two classes of phenomena—the magnetic and electric—are recognized as distinct emanations of a single fundamental force, pervading all nature. As we shall shortly learn, it was not until 1819 that the truth of this bold speculation was established by Oersted's discovery of electro-magnetism, while the subsequent researches and discoveries of Michael Faraday showed an even closer connection between the two sciences.

Gilbert showed that in addition to amber and tourmaline there was a wide variety of substances—such as spars, gems, fossils, glass, resin—that were capable of being electrically excited. He was the first to show that a moist state of the atmosphere was unfavourable to the production of (frictional) electricity. To test the properties of the varying substances, he made use of a light balanced needle that turned freely on a pivot.

De Magnete aroused considerable interest in scientific circles and it was rightly considered to be a most important contribution to physical science, presenting a pure specimen of inductive reasoning. Gilbert's pioneer work for wireless was such that, as Dryden said, " Gilbert shall live till lodestones cease to draw ".

Gilbert died of the plague on the 30th November, 1603.

IV

During the sixteenth, seventeenth, and eighteenth centuries suggestions were made by several writers to use a kind of magnetic wireless telegraph based on the sympathy supposed to exist between needles touched by the same magnet or lodestone. By this system, it was claimed, communication could easily be maintained between distant points, for every movement imparted to one of these needles would immediately induce similarly sympathetic movements in the other.

It is not possible to say with whom this fantastic idea originated, but it has been traced as far back as Baptista Porta, the Neapolitan philosopher. In his book he tells us that "owing to the convenience afforded by the magnet, persons can converse together through long distances".[1] In a later edition (1589) he is more explicit, saying, "I do not fear that with a long absent friend, even though he be confined by prison walls, we can communicate what we wish by means of two compass needles circumscribed with an alphabet".

Other writers blindly followed Porta and, one after another, repeated the wild statements about the sympathetic needles without question. Perhaps the most widely read was Famianus Strada, an Italian Jesuit and historian, who in 1617 published a version of the sympathetic telegraph that has served as the basis for similar statements by numerous successive writers even in comparatively recent times.

> "Let there be two needles provided of an equal length and bigness, being both of them touched by the same lodestone. Let the letters of the Alphabet be placed on the circles on which they are moved at the Points of the Compass under the needle of the Mariner's Chart. Let the Friend that is to travel take one of these with him, first agreeing upon the days and hours wherein they should confer together; at which times, if one of them move the needle, the other needle, by sympathy, will move on to the same letter in the other instantly, though they are ever so far distant. And thus by several Motions of the needle to the Letters, they may easily make up Words or Sense which they have a mind to express." [2]

The great Kepler seems to have believed in the efficacy of the sympathetic telegraph,[3] but Galileo would have none of it.

> "You remind me," he makes Sagredo say, "of one who offered to sell me a secret art, by which, through the attraction of a certain magnet needle, it would be possible to converse across a space of two or three thousand miles. And I said to him that I would willingly become the purchaser, provided only that I might first make a trial of the art, and that it would be sufficient for the purpose if I were to place myself in one corner of the room and he in the other. He replied that in so short a distance the action would scarcely be discernible, whereupon I dismissed the fellow, saying that it was not convenient for me just then to travel into Egypt or Muscovy, for the

[1] *Magica Naturalis* (Naples, 1558), p. 88.
[2] *Prolusiones Academicae*, Lib. II, prol. 6.
[3] See Fournier's *Le Vieux-Neuf* (Paris, 1857), vol. i, p. 200.

purpose of trying the experiment, but that if he chose to go there himself I would remain in Venice and attend to the rest." [1]

In this connection may be mentioned a remarkable prophecy of wireless made (in 1665) by an ardent and keen-sighted philosopher, Joseph Glanvill, F.R.S.:

> "I doubt not," he says, "but posterity will find many things that are now but rumours, verified into practical realities. . . . To them that come after us it may be as ordinary to buy a pair of wings to fly into the remotest regions as now a pair of boots to ride a journey. And to confer at the distance of the Indies by sympathetic conveyances may be as usual to future times as to us in a literary correspondence . . . 'tis no despicable item that by some . . . way of magnetick efficiency it may hereafter with success be attempted . . . ." [2]

V

Up to the latter part of the eighteenth century only one form of electricity was known. This was called "static" electricity, as distinct from "current" electricity. As every schoolboy learns, static electricity is produced by rubbing together two substances such as a glass rod and a piece of flannel. The glass then becomes charged and in this state will attract feathers or similar light objects. The experiment may also be performed with the vulcanite mouthpiece of a pipe and pieces of paper picked up (Fig. 1). Static electricity cannot be used to ring electric bells or to do other similar work, and it is of little or no interest, except for experimental purposes.

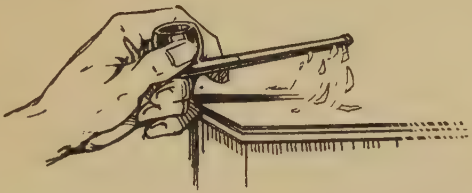

FIG. 1—PIPE MOUTHPIECE ATTRACTING LIGHT OBJECTS

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The fact that amber, when rubbed, possesses the power to attract light objects was known in very early times. Thales, one of the seven wise men of Greece, mentions it six hundred years B. C., ascribing the property to some living principle, some soul, that was roused to action by friction. In the spirit of the age amber was thus declared to be sacred, as was the lodestone for a similar reason.[1] Aristotle, Pliny, and other Greek and Roman writers also refer to the matter [2] and Theophrastus (B. C. 321) speaks of *lapis lyncurius*, the ancient name for tourmaline, as having a similar property to amber, and mentions that in addition to attracting straw and leaves it will attract also small particles of copper or even iron.[3] The ancient Persian name for amber *Káhrubá*, meaning " an attractor of straw ", shows that its peculiar properties were recognized in early times, as in the case of the magnet, *Ahang-rubá*, " attractor of iron ".[4]

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[1] *Dialogo sopra i due Massimi Sistemi del Mondo* (1632), p. 88.

[2] *Scepsis Scientifica*, ch. xxi.

Kuopho, a Chinese physicist, wrote in the fourth century :

> " The attraction of a magnet for iron is like that of amber for the smallest grain of mustard seed. It is like a breath of wind, which mysteriously penetrates through both and communicates itself with the rapidity of an arrow."

No attempt was made to study the subject, however, until Dr. Gilbert collected the scattered fragments, as we have already seen. He consolidated them into the nucleus of a new science, to which he gave the name " Electricity ", from the Greek word *elektron*, signifying amber.

Gilbert was followed by several workers, including the celebrated Robert Boyle, who published the results of his experiments in 1675.[5] Otto Guericke, Burgomaster of Magdeburg and inventor of the air-pump, constructed (in 1671) the first electrical machine, with which he produced greater quantities of electricity than had previously been possible. The machine consisted of a globe of sulphur mounted on an axis and excited by the application of a cloth. With it he discovered that strong electrification was accompanied by a

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[1] Aristotle : *De Anima*, i, 2.

[2] Pliny, Book XXXVII, ch. iii.

[3] *De Lapidibus*, p. 124.

[4] In an old Persian romance, *The Loves of Majnoon and Leila*, the lover thus describes his adored : " She was as amber, and I but as straw. She touched me and I shall ever cling to her ".

[5] *Experiments and Notes about the Mechanical Origin or Production of Electricity.*

WILLIAM GILBERT
(1540-1603)

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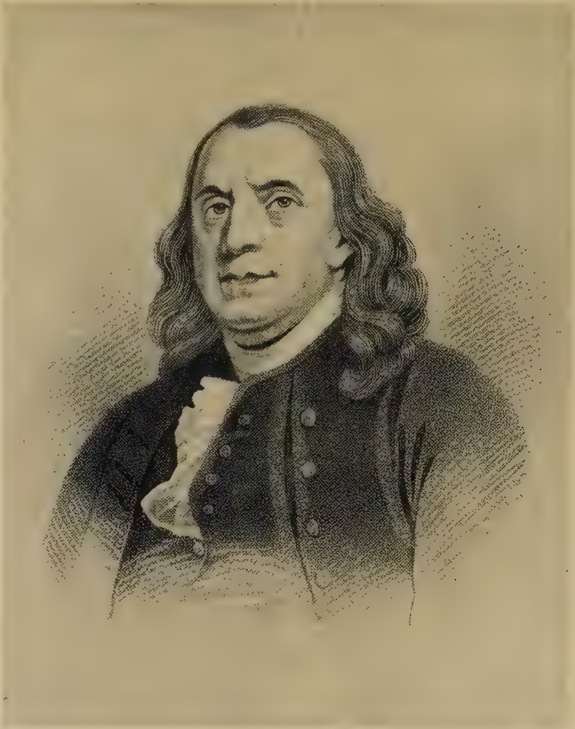

BENJAMIN FRANKLIN
(1706-1790)

"hissing noise and gleaming light", and this was the first recorded electric spark discharge. Guericke discovered electrical repulsion and the fact (but not the principle) of induction.[1]

In 1724 the remarkable Stephen Gray, a pensioner of Charterhouse, discovered the principle of electric conduction and insulation, and unknowingly used in his experiments apparatus that had all the essentials of a crude form of electric telegraph. He found that packthread or twine could be made to conduct electricity, and he even succeeded in producing motion in light bodies at a distance of 765 ft., the object of the experiment being to ascertain the distance to which an electric force could be transmitted. Probably the world does not know of more than a small fraction of the experiments made and the results obtained by Gray, nor how much knowledge died with him. He published the records of some of his experiments, and dictated an account of the rest of them on his death-bed. He was an indefatigable experimenter, and in the course of his investigations did many curious things, not the least of which was "hanging up boys by the neck and heels to find out whether they would transmit the electric effluvia". Latterly, his experiments became so uninteresting to the boys that they had to be replaced by roosters![2]

It was Dufay in France who, in 1733–7, made the important discovery that there are two kinds of electricity, one produced by glass and the other by resin, and these he named vitreous and resinous. Desaguliers (1683–1744), born in France but resident in London, divided matter into two classes, "electrics", bodies excitable by friction; and "non-electrics", those that could not be excited but that would receive a charge from an electric. He was the first to use the words "conductor" and "non-conductor" in the same sense as they are used to-day.

Sir Isaac Newton and Hauksbee (between 1705 and 1711) had made some experiments with a glass globe machine, but this method of generating frictional electricity had unfortunately been discontinued by workers in favour of the glass tube and silken rubbing-cloth used by Gray. In 1741, however,

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[1] *Experimenta Nova Magdeburgica* (Amsterdam, 1672), Book IV, ch. xv.

[2] *Kent*, No. 24, p. 220.

Hausen of Leipsic and Boze of Wittemburg reintroduced the glass globe machine and their improvements resulted in machines of greater power and efficiency. Boze added a cylinder of tin or iron which, suspended by silken cords, acted as the prime conductor. Winkler, also of Leipsic, substituted a wooden cushion for the hand of the operator, previously employed to excite the globe. In 1742 Gordon at Erfurt substituted a glass cylinder for the globe and so increased the power of the machine that he was able to kill birds at the end of an iron wire 250 yards in length.[1]

VI

One of the most important discoveries of this time, and one that has, perhaps, an even more direct connection with the fundamental principles of wireless, was the Leyden jar. This discovery (11th October, 1745) has been variously claimed for Musschenbröck, a celebrated professor at Leyden; for Cuneus, a rich citizen of Leyden; and for Von Kleist, Dean of the Cathedral at Kamin, in Pomerania. Von Kleist, at any rate, has priority in the matter of making his discovery public, but his account (given in a letter to Dr. Leber Kuhn, dated 4th November, 1745) is somewhat obscure.

> " When a nail or piece of brass wire is put into a small apothecary's phial and electrified," he wrote, " remarkable effects follow, but the phial must be very dry and warm. I commonly rub it over beforehand with a finger on which I put some powdered chalk. If a little mercury or a few drops of spirits of wine can be put into it the experiment succeeds the better. As soon as this phial and nail are removed from the electrifying glass, or the prime conductor to which it hath been exposed is taken away, it throws out a pencil of flame so strong that with this burning machine in my hands I have taken above sixty steps in walking about my room. When it is electrified strongly I can take it into another room, and then fire spirits of wine with it.
>
> " If while it is electrifying I put my finger or a piece of gold, which I hold in my hand, to the nail, I receive a shock that stuns my arms and shoulders. A tin tube, or a man placed upon electrics, is electrified much more strongly by this means than in the common way. When I present this phial and nail to a tin tube which I have, fifteen feet in length, nothing but experience can make a person believe how strongly it is electrified. Two thin glasses have been broken by the shock.

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[1] Priestley: *History of Electricity*, p. 64.

> "It appears to me extraordinary that when this phial and nail are in contact with either conducting or non-conducting matter, the strong shock does not follow. I have cemented it to wood, glass, sealing-wax, etc., which I have electrified without any great effect. The human body, therefore, must contribute something to it. This opinion is confirmed by observing that, unless I hold the phial in my hand, I cannot fire spirits of wine with it."

In January 1746 Cuneus accidentally made a similar discovery. He was working with Musschenbröck and Allamand, who had noticed that electrified bodies quickly lost their charge, which they supposed was abstracted by the air itself. They believed that if they could surround the electrified bodies with an insulating substance, so as to prevent their contact with the atmosphere, they would be able to preserve the charge for a longer period. They determined therefore to charge water contained in a glass jar, which would act as the insulator, and thus obtain a greater electrical charge than had previously been possible.

In carrying out the subsequent experiments, Cuneus held the glass jar in one hand, and disengaging the wire from the electrical machine, received a startling shock. He was filled with the utmost consternation and dropped the glass jar. Musschenbröck quickly repeated the experiment with similar results [1]—in fact, in a letter to Réaumur he said he lost his breath and was two days before he recovered from the effects of the shock and the terror! He added that he would not repeat the experiment for the whole kingdom of France. On the other hand, Boze seems to have desired to become the first electrical martyr, expressing the wish that he might die by the shock so that the account of his death might furnish a paper for the memoirs of the French Academy!

The original glass jar was improved (in 1746) by Dr. Bevis when he coated part of it with sheet lead or tin-foil and suspended from its cover a metal chain, and in this form it practically remains to-day. Bevis's next step was to dispense with the water, which he replaced with shot, and obtained a charge of greatly augmented force. He realized that the seat of the electric influence was the surface of contact of the metal, and anticipated that the form of the jar was not connected in any way with the principles involved. To prove this he took a pane of glass, and coating each side with tin-foil to within an inch of the edge, charged it from an electrical machine, obtaining from it as strong a shock as from a jar with the same extent of coated surface.

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[1] Priestley: *History of Electricity*, p. 75.

The London apothecary and physician Dr. (afterwards Sir William) Watson, who had already showed that the force of the shock was increased by diminishing the thickness of the glass, now established the law that the force of the charge was proportional to the extent of the coated surface and to the thinness of the glass.[1]

Apart from some experiments in regard to the transmission and velocity of electricity, the Leyden jar was regarded as being little more than a scientific novelty, and was talked about over the dinner-tables of polite society as were X-rays and radium when they were discovered. The original experiments were repeated everywhere, and excited general wonder as being " a prodigy of nature and philosophy ", and large numbers of " electricians " wandered over Europe, enriching themselves and gratifying curiosity by selling " shocks " to all and sundry. The experimenters, relating their " experiences ", were unconscionable exaggerators. Gralath, for instance, maintained that the discharge " gave some people the nose bleed ", whilst even Musschenbröck, when he first wrote about his observations to Réaumur, referred to " a new but terrible experiment " by which his arm and body " were affected in a manner more terrible than I can express ". The Abbé Nollet, in France, used to kill birds with the discharge to entertain the ladies of the court. Gralath tried to emulate him, but succeeded in killing only beetles and worms. In his effort to obtain still stronger effects he hit on the plan of grouping several jars together, and then succeeded in killing birds easily. The Abbé Nollet was certainly the most daring and imaginative of all these experimenters. To amuse the French king, he sent a discharge through 180 guardsmen, making them jump simultaneously! Later he passed a " shock " through a number of Carthusian monks arranged in a circle 5,400 ft. in diameter. " This was done by means of iron wires of proportionable length between every two, and consequently far exceeding the line of the 180 guards. The effect was such that when the two extremities of this long line met in contact with the electrified vial, the whole company at the same instant gave a sudden spring, and all equally felt the shock." He electrified seeds, vegetables, and animals, and noted the effect with painstaking accuracy, thus anticipating the principle of modern electroculture research.

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[1] Priestley: *History of Electricity*, p. 82.

When the novelty of killing insects and birds and of "shocking" soldiers and monks wore off, serious study began of this remarkable apparatus with the strange property of storing up electrical energy. The Leyden jar enabled various scientific societies and individual workers to enter on a long course of experiments in transmitting the electric current over wires of varying lengths and in determining its speed of travel. These experiments may be said to have culminated (on 5th August, 1748) in a series of trials at Shooter's Hill, when Dr. Watson formed a circuit of two miles of wire. Both ends were led to the same room, and as a result of his experiments Watson came to the conclusion that the time occupied by the passage of electricity along 6,138 ft. of wire was altogether inappreciable.[1]

During this time the theory of the Leyden jar remained obscure, and was not elucidated until the matter was investigated by Franklin, that remarkable combination of scientist and statesman.

VII

Benjamin Franklin (*b*, Plate I) was born at Boston, U.S.A., on 17th January, 1706. His ancestors had resided on their own property at Ecton, Northamptonshire, for 300 years, but Franklin's father emigrated to New England in 1685. Benjamin was intended for the Church, but his inclinations did not lie in that direction. He was very fond of reading, and studied everything that came in his way. His knowledge was soon considerable, and the story is told how he once astonished his parents with the statement that he had just swallowed some "acephalous molluscs"! His father laid hold of him in great alarm and called for help. In spite of Benjamin's protests, his mother poured half a gallon of hot water down his throat, and he was then held upside down for the "poison" to run out! As soon as the boy could speak he explained that "acephalous molluscs" were only oysters, after which his father took a strap and gave him a sound "larruping". It is said that after this incident Benjamin's language was singularly clear and explicit!

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[1] *Phil. Trans.*, vol. xlv (1878).

His love of books finally caused him, when 12 years of age, to apprentice himself to a printer. Here he was treated badly, and five years later he determined to make a change, so he ran away. He reached Philadelphia, 400 miles distant, practically penniless, though he had previously sold all his books to raise money for his adventure. He soon obtained work, however, and Sir William Keith suggested he should set up business on his own account. Thinking he could purchase types and printing presses to better advantage in England, he set sail for that country, but found on his arrival that Sir William had not sent the letters of credit nor the introductions he had promised. He was undaunted, however, and obtained work in London as a compositor, lodging first in Little Britain and later in Duke Street, Lincoln's Inn Fields. In 1726 he returned to America, where he first worked for his old master and then set up in business for himself as a printer, at the same time writing on a variety of subjects. He was a great worker, and was busy early and late. He established a newspaper, and began to prosper. He was appointed Clerk to the Assembly in 1736, and Postmaster in the following year. By 1750 he had amassed a considerable fortune and was elected a representative in the Assembly.

His attention was first directed to electricity in 1746, when he saw some experiments, which, however, were but imperfectly carried out. He repeated them himself, and soon after announced his theory of the identity of lightning and electricity. He submitted a paper to the Royal Society, but received no consideration from this august body, which did not even print his paper in its *Transactions*.

In July 1750 Franklin suggested the use of pointed iron rods as lightning conductors, to draw lightning from the clouds without noise or danger.[1] There was no building in

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[1] *Franklin's Complete Works* (London, 1806), vol. i, p. 172.

Philadelphia that was sufficiently lofty for an experiment, however, but it struck him that an ordinary kite might be used successfully, and in June, 1752, his historic experiment with a kite resulted. This was carried out in connection with a Leyden jar, to which the string was connected. Franklin flew his kite during a thunderstorm, and the string acted in a similar manner to a lightning conductor, the Leyden jar being charged by the difference in potential between the clouds and the earth. The Royal Society now recognized his work, made him a Fellow, and in 1753 awarded him the Copley Medal.

In connection with the Leyden jar, Franklin discovered the method of cascade connection that greatly increased the total discharge current. He also proved that the charges accumulate, not on the surface of the jar, but on the metallic coating, as had been suggested by Dr. Bevis. The experiment by which he showed this is both interesting and ingenious. He first charged a jar and then, insulating it, removed the cork and the wire by which the electricity was conveyed from the charging machine to the inside of the jar. On examining these and finding them free from electricity, he poured out the water into another jar, also insulated. This water was also found to be free from electricity. Fresh water was introduced into the charged jar in place of that poured out, and on placing one hand on the outside coating and the other in the water, he received a shock as strong as if no change had been made in the jar since it was first charged.[1]

No material change has been made in the form of the Leyden jar from the date of its invention, and even now it remains practically unaltered. In its early form it consisted of a glass jar, coated inside and out with tin-foil, and in its modern form the only alteration made was to use a coating of electrolytically deposited copper in place of the tin-foil.

When Marconi first signalled from Poldhu to Glace Bay he used a large battery of Leyden jars, which later were replaced with condensers.

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[1] Priestley: *History of Electricity*, p. 144.

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CHAPTER II

GALVANI, DISCOVERER OF ANIMAL MAGNETISM; VOLTA DISCOVERS CONTACT ELECTRICITY AND EVOLVES THE VOLTAIC BATTERY; OERSTED, THE PIONEER OF ELECTRO-MAGNETISM; AMPÈRE'S MATHEMATICAL ANALYSIS OF ELECTRICITY

UP to this point we have been considering only frictional or static electricity, but the discovery (in 1780) of current electricity by Galvani, an Italian doctor of medicine, paved the way for a more definite advance and for greater scope for pioneers of wireless. Luigi Galvani (*a*, Plate II) has been called "the luckiest of all famous men of science", for it is stated that by the purest accident he discovered the principle of the galvanic battery. Born on the 9th September, 1737, at Bologna, this Italian pioneer of science devoted himself to the study of theology, intending to become a monk. His father opposed his suggestion, however, with the result that he determined to become a doctor. He devoted himself so assiduously to his studies that he became one of the most brilliant surgeons of his time. His treatise on the formation of bones won for him (in 1762) the Chair of Anatomy at the University of his native city. He was then only 25 years of age, but he soon became famous as a skilful teacher and exponent of comparative anatomy.

It has often been erroneously stated that the experiments that were to make him famous were brought about through his wife, who was an invalid, and that to maintain her strength she was fed on a broth of frogs' legs, always prepared by Galvani himself. The story goes that one morning in 1790 he placed some freshly killed frogs on the table ready to make the broth, and his wife was surprised to notice that the limbs of the frogs were moving in a peculiarly convulsive manner. She called Galvani, who decided that this movement was caused by the current from an electrical machine conducted to the frogs' legs through an anatomical knife that happened to be lying near at hand.[1]

For a hundred years or more before Galvani's time, however, there are numerous records of experiments of a character closely resembling those that Galvani carried out, and there seems no reason to think that he was ignorant of them. In 1671, for instance, Richter noticed that the *Gymnotus electricus*—an eel-like inhabitant of the warmer regions of Africa and South America, and discovered by Richter when in Cayenne on an astronomical expedition—was able to produce by its shocks a sympathetic quivering in dead fish near it. In 1678 Swammerdam produced contractions in the muscle of a frog by holding it against a brass ring, from which it hung by a silver wire.[2] Du Verney, a celebrated anatomist, in 1700, and Caldani, in 1757, described "the revival of frogs by electric discharges". Du Verney "showed a frog just dead, which, in taking the nerves of the belly that go to the thighs and legs, and irritating them a little with a scalpel, trembled and suffered a sort of convulsion. Afterwards he cut the nerves, and holding them a little stretched with his hand, he made them tremble again by the same motion of the scalpel".[3] Alexander Stuart, in England, carried out exactly similar experiments in 1732, producing contractions by exciting the spinal marrow of the frog.[4] Sulzer, in Berlin (1767), and Domenics Cotugno, in Naples (1784), similarly had galvanism within their grasp, but failed to make the great discovery.

Galvani was an ardent student of anatomy and physiology, and as such it is indeed inconceivable that he would be unaware of some, if not all, of the experiments of these earlier workers. Although, as we have already seen, he is supposed to have made an accidental discovery of galvanism in 1790, Gherardi, his biographer, tells us that in 1780 he was experimenting on the muscular contractions of frogs under the influence of electricity. This is confirmed by two papers on the subject, dated 22nd April, 1773, and 20th January, 1774, which further show that Galvani's acquaintance with frogs was made even before 1780.[1] It was on the 6th November of that year that he first noticed peculiar convulsions in the body of a frog that he was preparing for his experiments, which convulsions took place on each occasion when a spark appeared in an electrical machine with which some friends were amusing themselves. The same phenomenon, first observed by Wilson in Dublin in 1746, had been explained by Lord Mahon in 1779, although it does not seem that Galvani was aware of either the discovery or the explanation.

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[1] The story seems to have been first invented by Alibert, in his *Éloges Historiques de Galvani* (Paris, 1802).

[2] Swammerdam: *Biblia Naturae*, vol. ii, p. 839.

[3] *Memoirs Royal Academy of Sciences at Paris* (London, 1742), vol. i, p. 187.

[4] *Phil. Trans.*, vol. xxxvii, p. 327.

II

Galvani next decided to further experiment by erecting a lightning conductor on the roof of his laboratory and connecting it by metal rods to the nerves of frogs and other animals, completing the circuit by connecting the frogs' legs to earth. A similar result took place, and the legs were convulsed with every flash of lightning. He continued his experiments during 1781–2, and described his discoveries in an unpublished paper on *The Nervous Force and its Relation to Electricity*. For four years he apparently abandoned his experiments, but on resuming his studies in 1786 his nephew, Camillo, who was assisting him in his work, detected something that led to the important discovery of galvanism.

On the 20th September, 1786, Camillo, having prepared some frogs for the usual experiments, hung them to the iron rail of the balcony outside the laboratory window. He was surprised to notice that when the wind moved the hanging legs, so that they touched the rail, they were convulsed as they were when subjected to a charge from the electrical machine or from the lightning conductor. Galvani dismissed the effect as being due to some unseen changes in the electrical state of the atmosphere, but after many experiments he found that the convulsions arose from the contact of the iron with the nerves and muscles of the frog. He further perceived that convulsions of greater intensity were produced by using

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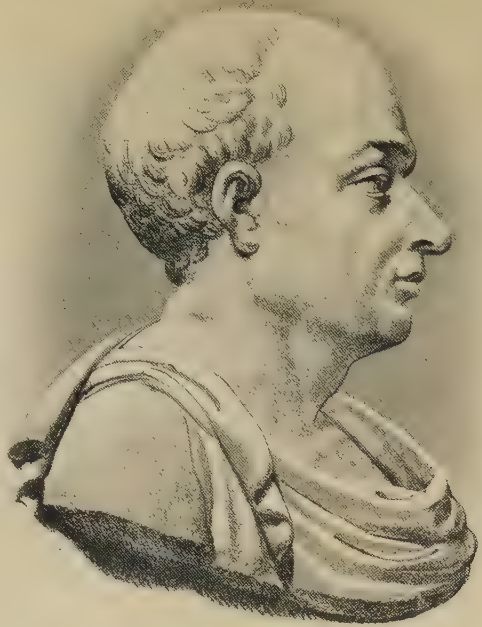
[1] *The Muscular Movements of Frogs' Legs* and *The Action of Opium on the Nerves of Frogs* (in *Bolognese Transactions*).

PLATE II



LUIGI GALVANI
(1737-1798)

ALESSANDRO VOLTA
(1745-1827)

different metals, such as iron and copper or iron and silver, which combinations became known as his " electric arc ".[1]

Galvani was of the opinion that the phenomena were caused by the union of a positive electrical charge of the nerve with a negative charge of the muscle. He thought that both charges resulted from the decomposition, at the junction of the nerves and the muscles, of a natural source of electricity that he supposed to exist in all animals. He was wrong in his assumption, of course, and it was left to Volta, of whom we shall read later, to show that the cause of the convulsive movements of the frogs' legs was due to the fact that the two metals of Galvani's " electric arc " generate electric currents of different forms. To-day, when it is desired to illustrate Galvani's experiment, it is usual to place the nerve and muscle of the frog or other animal in series with a small battery.

Although incorrect in explanation of his discoveries, Galvani's work opened up an entirely new field of experiments. It showed, for instance, a new method of generating electricity, which previously was only to be obtained by frictional electrical machines, and it fascinated physiologists, who now believed that in electricity they had found the great vital force by which the decrees of the understanding and the dictates of the will were conveyed from the brain to the various parts of the body.

When Napoleon invaded Italy, Galvani lost his professorship at Bologna on refusing to swear allegiance to the new Cisalpine Republic. He was relieved of his position and stripped of his titles, and although a special edict was published later by the government reinstating him without penalty or oath, restitution came too late. The death of his wife, whom he dearly loved, together with the poverty following his degradation, had broken his heart, and he died in his native town on 4th December, 1798, without having again occupied the Chair of Anatomy that he had for ever made illustrious.

A statue in his honour, erected in 1879 at Bologna, depicts him at the moment when the frog's muscles are revealing to him his great discovery.

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[1] The results of these experiments were published in a paper printed in the *Bolognese Transactions*, 1791.

III

Another Italian, Alessandro Volta, of Como, continued the master's unfinished experiments in current electricity with such success as to have been called the father of modern electricity. Volta (*b*, Plate II), who was eight years Galvani's junior, was born at Como on 19th February, 1745, being descended from a noble Milanese family. As a boy he was brilliant and versatile, and decided to become a poet, but at the age of 18 he took up the study of electricity. He invented an apparatus for generating electricity by induction, and commenced experiments with a view to investigating the action of the Leyden jar, which at that time was the only known appliance by which electricity could be stored. Through his theory of the Leyden jar he was appointed (in 1774) Professor of Physics at Como. He travelled through England and France in furtherance of his electrical studies, and on hearing of Galvani's discovery in connection with the frogs' legs he made further experiments that resulted in the discovery (by Fabroni in 1792) that electricity may be generated by chemical means.

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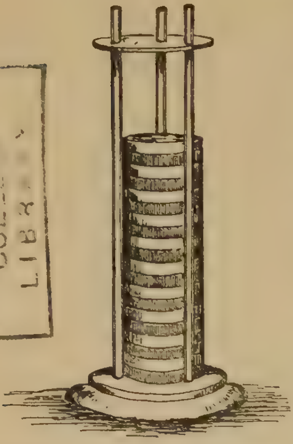

Fig. 2—The Voltaic pile

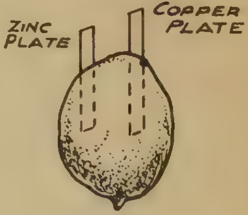

Fig. 3

Anyone may experience a similar effect to that discovered by Volta by placing a silver and copper coin above and below the tongue. When the two coins touch, a slightly acid taste will be noticed. A similar experiment may be performed with a strip of copper and a strip of zinc in a lemon.

Experiencing the necessity for collecting galvanic electricity in considerably greater quantities than could be obtained from the mere contact of a single pair of dissimilar metals, Volta evolved (in 1796) the "Voltaic pile", consisting of copper and zinc discs placed alternatively in column form, but prevented from touching one another by pieces of moist cloth (Fig. 2). Volta found that the pile gave feeble charges of positive and negative electricity, for the supply was available in a continuous current, being renewed as fast as it flowed away. This type of electricity therefore became known as "current electricity".

Volta described his pile in a letter, dispatched on 20th March, 1800, to Sir Joseph Banks, President of the Royal Society. It had scarcely been announced when the compound nature of water was accidentally discovered by its aid (on 2nd May) by Sir Anthony (then Mr.) Carlisle and W. Nicholson.

Volta's discovery was followed by a long and heated controversy as to the origin of the electricity thus produced, which—it was finally decided—was due to chemical action. The voltaic pile was later replaced by the voltaic cell, a vessel containing dilute acid, in which two kinds of metal—generally copper and zinc—were placed and an electric current obtained (Fig. 4).

That Volta's discoveries were of the greatest importance was at once recognized in the scientific world, and in 1801 Bonaparte summoned him to Paris in order to see for himself his experiments. He conferred upon him the order of the Legion of Honour and the Iron Crown, and nominated him a Count and Senator of the kingdom of Italy. Three years later Volta resigned his professorship, and he died at Como 5th March, 1827, having published nothing else of importance. Subsequently a medal to his memory was struck, a monument erected, and a niche in the façade of the public school at Como, between the busts of Pliny and Giovio, natives of the town, was filled with his bust.

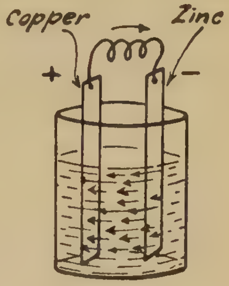

FIG. 4

A simple voltaic cell, in which copper and zinc plates are immersed in dilute sulphuric acid. The current passes from the zinc to the copper as indicated by the arrows.

IV

Although a strong resemblance between electricity and magnetism was suspected as early as 1734 by Swedenborg, and 14 years later by Beraut, Professor of Mathematics in the College of Lyons, it was not until 1820 that Oersted showed experimentally that a connection existed.

Hans Christian Oersted (*a*, Plate III) was born on 14th August, 1777, at Radkjobing on the Danish island of Langeland. Here his father carried on an apothecary's business, and Hans was brought up to follow this profession. A German barber taught him German, and his (the barber's) wife taught him to read and write. A minister's son taught him Greek, Latin, and French. At the age of 12 he was apprenticed to his father with a view to becoming a chemist, and in 1793 he was sent to the University of Copenhagen to study Pharmacy. With a passion for knowledge, he absorbed everything that came his way, and, passing his examinations in Pharmacy, took a prize in Medicine, and became a Doctor of Philosophy. He was then appointed assistant to the Professor of Surgery, and distinguished himself in chemical research. In 1800 he was one of the first to use the newly invented electric battery in connection with a research into the acids and alkalies set free by the electric current.

When 24 years of age Oersted won a travelling scholarship, and for five years travelled through Holland, Germany, and France, gathering scientific knowledge. On his return he was appointed (in 1806) Professor of Physics at Copenhagen University. After having devoted a great part of his life to the study of electricity and magnetism, and having held many scientific appointments and honorary offices, and attained numerous scientific distinctions, he died on 9th March, 1851.

Although Oersted was the pioneer of the science of electromagnetism, he is better remembered by his famous discovery that a freely swinging magnet, such as a compass needle, is deflected if placed near a wire through which an electric current is flowing. As in the case of Galvani and the frog's legs, Oersted's epoch-making discovery came about quite by accident. During the winter of 1819–20 he demonstrated the principles of the electric current at private lectures to a few advanced students, and in April, 1820, seems to have been arranging a compass needle to observe whether there were any deflections during a storm. He placed the compass near a platinum wire, through which a current was passed, and noticed that the magnetic needle was at once deflected (Fig. 5).

This, the pioneer discovery in electro-magnetism, seems to have been made as follows: "Professor Oersted was a man of genius, but he was a very unhappy experimenter," wrote Professor Christian Hansteen to Michael Faraday. "He could not manipulate instruments and must always have an assistant, or one of his auditors who had easy hands, to arrange his experiment. I have often in this way assisted him." In the eighteenth century there was a general thought that there was a great conformity, and perhaps identity, between the electrical and magnetical forces, and it was a question how to demonstrate it by experiments. Oersted tried to place the wire of his galvanic battery perpendicular (at right angles) over the magnetic needle, but remarked no sensible motion. Once, after the end of his lecture, as he had used a strong galvanic battery in other experiments, he said: "Let us now once, as the battery is in activity, try to place the wire parallel with the needle." As this was done he was quite struck with perplexity by seeing the needle make a great oscillation (almost at right angles with the magnetic meridian). Then he said: "Let us now invert the direction of the current," and the needle deviated in the contrary direction. Thus the great discovery was made, and it has been said—not without reason—that "he tumbled over it by accident". He had not before any more idea than any other person that the force should be transversal.[1]

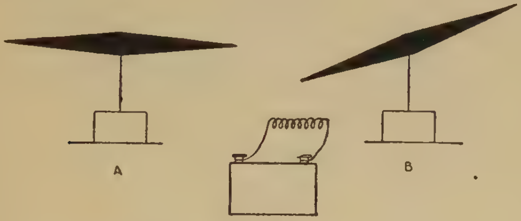

FIG. 5

A. Magnetic needle in normal position.
B. The same deflected by an electric current.

Oersted apparently did not at first clearly understand the full significance of his discovery, and took no immediate steps to publish it. "Although the effect was unquestionable," he says, "it appeared to me, nevertheless, so confused that I deferred a minute examination of it to a period at which I hoped for more leisure."[1]

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[1] Iles: *Inventors at Work*, pp. 290–1.

Oersted experimented to see that the nature of the wire did not influence the results, and later announced that the phenomenon was due to what he called "the electric conflict" around the wire. He noticed the fact that the compass needle places itself more or less transversely to the wire, the direction depending on whether the wire is above or below the needle and whether copper or zinc ends of the voltaic pile are connected to it. He recognized the existence of the magnetic field around a conductor, and by this discovery showed that an electric current possesses magnetic properties similar to those of the lodestone of the ancients. The two forces, which had previously been regarded as separate phenomena, were thus shown to be intimately connected.

Oersted first published his discovery in an essay written in Latin and dated 21st July, 1820.[2] His essay, *Experiments in the Effect of a Current of Electricity on the Magnetic Needle*, describes the action that he considers takes place around the wire.

> "It is sufficiently evident," he wrote, "that the electric conflict is not confined to the conductor but is dispersed pretty widely in the circumjacent space. We may conclude that this conflict performs circles round the wire, for without this condition it seems impossible that one part of the wire when placed below the magnetic needle should drive its pole to the east and when placed above it to the west."

For his work Oersted was awarded the Copley Medal of the Royal Society.

To-day the magnetic property that Oersted discovered is used to detect the presence of electric currents, in the form of a "galvanometer", an instrument consisting of a delicately poised magnetic needle placed in the centre of a hollow coil of wire. When a current is passed through the coil, it affects

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[1] Tyndall's (1876) Lectures on *Voltaic Electricity* at the Royal Institution.

[2] An English translation is given in *Annals of Philosophy*, November, 1821, and also in the *Journal of the Society of Telegraph Engineers*, vol. v, pp. 459–69.

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HANS CHRISTIAN OËRSTED
(1777-1851)

ANDRÉ MARIE AMPÈRE
(1775-1836)

the needle exactly in the same way that Oersted's needle was deflected by the current in the neighbouring wire. The amount of deflection varies according to the strength of the current, and is recorded by a pointer that moves over a graduated scale.

Incidentally the discovery of the intimate connection between the lodestone and the electro-magnet was a striking substantiation of a theory that Oersted had formed while on his five years' travels. This was that all the forces of Nature are identical in their ultimate nature, a doctrine that he expounded at great length when he took up his professorship at Copenhagen. The remarkable part of this theory was shown in an even more striking degree when Faraday developed Oersted's experiments and when Clerk-Maxwell showed that light was also an electro-magnetic phenomenon.

Einstein believes that gravitation and electricity are one and the same, and physicists are endeavouring to make the atom yield its secret of electrical centres of energy. Oersted could not know of these things, nor could he have more than a fraction of the advanced knowledge we possess when he propounded his theory. Yet perhaps, after all, his theory will prove to be the fact. Some day it may be possible for us to reduce all the " forces of Nature " to terms of electrical energy.

V

Oersted's paper aroused great interest in the subject, and experiments were made in almost every laboratory to follow up and demonstrate more clearly the connection between magnetism and electricity. Famous men in almost every country took up the pursuit of knowledge. In England, Davy, Faraday, Cumming, and Sturgeon. In America, Henry. In Europe, Arago, Seebeck, Schweigger, and De la Rive, as well as others. Of all these, however, the most famous was Ampère, a young French scientist who was studying electricity at the time Volta was conducting his experiments.

André Marie Ampère (*b*, Plate III) was born at Poleymieux, near Lyons, on the 22nd January, 1775. At an early age he showed a wonderful talent for arithmetical calculation, and worked out long arithmetical problems with pebbles even before he had been taught his figures! In his youth he had no tutor, but was assisted in his studies by his father, who procured for him the necessary books. In 1789 the French Revolution broke out, and the ideals of the revolutionaries filled young Ampère with enthusiasm. He received a tremendous shock, however, when his father was put to death by the revolutionaries, and the tragedy made a deep and melancholy impression on him. For almost a year he remained in a state of stupor, not even recognizing the places where he had been brought up. Gradually he recovered his normal spirits, however, chiefly through reading some verses of Horace's *Ode to Licinius*. As soon as he felt able to do so, he endeavoured to find some solace by studying botany. From 1794 to 1797 he immersed himself in literature, and having devoured all the Latin poets he turned his attention to Greek. He followed literature with a study of science and art, but seemed unable to plan out any definite line of work, until at last he decided to devote himself exclusively to a study of physics.

In the meantime (in 1799) he had married Mlle Julie Carron. His son, born in the following year later became an intellectual literary man and a member of the Academy. Marriage necessitated Ampère choosing a profession, and he decided on a scientific career. In 1801 he became Professor of Chemistry and Physics at Bourg, and in the following year, at the age of 27, published a mathematical paper. In 1804 his wife died, and in the same year he was appointed Professor of Mathematics at Lyons. In his youth he had always had a considerable interest in mathematical subjects, and in his later years remarked that he knew as much about mathematics when he was 18 years of age as at any time afterwards. In 1805 he entered the Polytechnic at Paris, and in 1809 attained the high post of Professor of Mathematical Analysis and Mechanics. In 1814 he became a member of the Academy of Sciences and Professor of Physics in the College of France. Subsequently he enjoyed numerous distinctions, including the Legion of Honour and Fellowship of the Royal Societies of London and Edinburgh.

It was during a tour of inspection that Ampère, 61 years of age, worn out by toil but still in full possession of his mental faculties, fell ill at Roanne. He endeavoured to continue with his tour, but arriving at Marseilles, had to take to bed. He died in the College of that town on the 10th June, 1836.

Ampère's work was considerable, and had a marked effect on scientific progress. His fame as a pioneer of wireless is based more particularly on his application of the highest branches of mathematical analysis to electricity and magnetism and on his study of electro-magnets. His researches may be said to have largely prepared the way for Faraday's subsequent experiments.

As we have already learned, Oersted had discovered (in 1819) the effect of an electric current upon a magnetized needle, and although he published his results on 21st July, 1820, the Academy of Sciences did not hear of the experiments until the following 11th September. Immediately Oersted's discovery was announced, Ampère began an investigation of electro-magnetism, and on the 18th September he read a paper before the Academy explaining the law that determines the position of the magnetic needle in relation to the electric current. He also described several instruments that he proposed to construct, particularly spiral wires through which he intended to transmit an electric current. Then, he claimed, the wires would acquire the properties of magnets, and would retain those properties as long as a current continued to be transmitted through them.

In his paper Ampère also announced that he had noticed that the voltaic pile itself affected the magnetic needle in the same manner as did the connecting wire. He showed that this effect was consistent with the theory that the electric current completes a circuit back to the pile from which it originated. He advanced his brilliant theory that the attractive and directive power of a magnet is due to electric currents that are constantly circulating around its molecules, in planes at right angles to a line joining the poles. He announced that the position of the poles, on the one side or the other of these planes, depended on the direction of the revolving current.[1] In his paper *New Discoveries in Magnetism and Electricity* he suggested using the effect of an electric current upon a magnetized needle in order to transmit signals

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[1] *Annales de Chimie et de Physique* (Paris, 1820), vol. xv, pp. 59 and 170.

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from one point to another. The French thereby claim that he was the originator of the conception of the electric telegraph. Of his suggestion, however, Steinheil wrote : " Ampère departs so totally from the desirable principle of simplicity that upwards of 60 metallic connections would be required for his telegraph."[1]

Ampère, whose name is one of the most illustrious in French science, is described as having been remarkably candid and ingenuous. Possessed of a very modest fortune, he gave freely to those in need, and lavished it on the construction of new apparatus.

In France his absent-mindedness is almost proverbial, and is well illustrated by an incident that occurred during a meeting of the Academy of Sciences. Ampère was reading one of his papers, and his audience was listening with rapt attention. Suddenly there was an unusual disturbance, and a general murmur was heard as a stranger, attired in a dark blue dress-coat, entered the hall. The stranger quelled the excitement with a sign, and taking a vacant seat on the platform, listened undisturbed to the lecturer.

When he had read his paper, Ampère returned quietly to his place, not having noticed the interruption. Great was his astonishment, however, when he found his seat occupied by the stranger. Too modest to protest, Ampère walked round his seat and coughed once or twice, but the stranger failed to take the hint, appearing to be lost in thought. Ampère then remarked loudly to one of his colleagues that it seemed to be wrong that a stranger could annex a member's chair without explanation or apology. The only response was a quiet smile, which so mystified Ampère that he overcame his timidity and addressed himself to the President.

" Mr. President," said he, " I must point out to you that a stranger has taken my seat."

" You are mistaken, my dear colleague," replied the President; " the person to whom you allude is no stranger, but a member of the Academy."

" Since when ? " asked Ampère.

" Since the 5 Nivôse, year VI," interjected the stranger.

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[1] Steinheil : *Telegraph Communication by Means of Galvanism*, in the *Annals of Electricity*, vol. iii, p. 448.

"And in what section, sir?" inquired Ampère, in an ironical tone.

"In the Mechanics Section," smilingly responded the intruder.

"This is a little too much," cried Ampère, as he snatched up a list of members of the Institute. Turning to the date mentioned, he read: "Napoleon Bonaparte, member of the Academy of Sciences, elected to the Mechanics Section on the 5 Nivôse, year VI."

Ampère, very upset at not having recognized the Emperor, was profuse in his apologies. The Emperor was much amused by this occurrence, however, and genially replied, "There, sir, you see what comes of not consorting with your colleagues! I never see you at the Tuileries, although, of course, I could easily compel you to come there, at least to bid me good day"!

When the meeting terminated, the Emperor approached Ampère, and taking his hand said, "As for you, my dear colleague, I shall expect you to dinner to-morrow. It will be at seven, and I shall place you next to the Empress—I tell you that, so that you will not mistake her for some one else!"

The sequel to this incident is typical of the absent-mindedness of the great scientist. On the following night the Imperial household did not sit down to table until eight o'clock. The Emperor had waited an hour for his colleague of the Academy, but Ampère had forgotten all about the invitation, and was unconcernedly absorbed in his work!

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CHAPTER III

ARAGO'S DISCOVERIES IN MAGNETISM; STURGEON DISCOVERS THE ELECTRO-MAGNET; HENRY PLACES THE SCIENCE OF ELECTRO-MAGNETISM ON A SOUND BASIS AND DISCOVERS INDUCTION

WHILST Ampère was pursuing his investigations into the behaviour of the magnetic needle, his illustrious countryman Arago was studying the state of a wire through which an electric current was transmitted.

Dominic François Arago (*a*, Plate IV) was born on 26th February, 1786, at Estagel, at the foot of the Pyrenees, and died on 2nd October, 1853, in Paris. He had a remarkable life, and one more in keeping with that of a merchant-adventurer or explorer than that usually associated with a famous savant and scientist. In his autobiography (which, unfortunately, extends only to the year 1830) Arago tells us how, in the first place, he contended successfully against all the influences of home, rejecting the course of life for which his father intended him and adhering unwaveringly to his own inclination to become a soldier. At that time officers were not permitted in the French Army unless the individuals had passed with credit the scientific and military courses of the famous Polytechnique. Admission to this celebrated school was not open, however, and candidates were required to undergo a severe and searching entrance examination. This did not deter young Arago, however, who threw himself into the study of Mathematics with characteristic impetuosity. At the age of 17 he was commended by his examiner, the illustrious Monge, and soon after entering the school was examined by Legendre, one of the foremost geometricians of the century, in which test he acquitted himself with honour.

He passed through the Polytechnique with the greatest distinction, having gained in the meantime the friendship of the most eminent men in Paris. When 19 years of age he was appointed secretary of the Paris Observatory. He assisted Biot in attempts to determine the refracting properties of different gases, out of which association sprang another of greater scientific importance—that of meridional measurements. This work resulted in considerable hardships and dangers, for Arago had to make his observations from the summit of one of the loftiest of the Catalonian Pyrenees, and suffered considerably from exposure. While Arago was in Majorca the French armies entered Spain, and as the inhabitants imagined that his geodetic signals were those of a spy, he had to take refuge from their fury in the castle of Belver. From here, after a narrow escape from death by poisoning at the hands of a furious and rascally priest, he escaped to Algiers. Embarking for France in an Algerine vessel, he was captured in the Gulf of Lions by a Spanish corsair, carried to Rosas, and brought back to Spain. Here he was confined first in a windmill, but later transferred to the hulks at Palamos, where his sufferings were very great. At last he was ransomed by a friendly chieftain and again set sail, but as the ship drew near the French coast a storm forced the vessel southward, and once again Arago landed in Africa! In the meantime his benefactor had been beheaded, and his cruel successor was on the point of throwing Arago into a slave prison when he was, very opportunely, himself hanged at the hands of some of his mutinous followers! After six months' time Arago again embarked, and on 2nd July, 1809, safely reached Marseilles with his instruments and charts complete and uninjured! He returned to Paris and—a thing previously unheard of—took his seat in the Academy of Sciences at the early age of 23. In 1830 he became the Academy's secretary, and contributed a multitude of treatises on almost every aspect of physical science.

It was Arago's work at the Observatory that led him to investigate magnetic phenomena—first in regard to the connection between the aurora and magnetic storms, and later between electricity and terrestrial magnetism. Working on Oersted's original discovery, Arago directed his own inquiries to endeavouring to determine the state of a wire through which a current was transmitted, his object being to discover whether every part of its surface was endowed with similar magnetic properties. He placed iron filings around the wire, and found that it attracted them so long as the current flowed and that they fell away instantly when the current was broken. He also found that if an electric current is passed through a coil of wire in which is placed a steel needle, the needle is not only attracted but is permanently magnetized—both of which discoveries were made independently by Davy in England at about the same time.

II

About this time, and resulting from Oersted's experiments, an important discovery was made by Schweigger of Halle. He announced on 16th September, 1820, that the deflection produced by the outward current from a battery, flowing through a wire over a needle, was the same as the deflection caused by the return current under the needle. He announced also that by causing the wire to proceed from and to the battery, above and beneath the needle, double the effect could be obtained. By giving the wire another turn around the needle the amount of deviation was again doubled. Three turns produced six times the effect; four turns, eight times, and so on, the deflection theoretically increasing in proportion to the number of convolutions. This discovery made possible the construction of voltmeters, galvanometers, and other similar instruments for measuring currents of electricity.

Schweigger's first instrument, which he named the "electromagnetic multiplier", was a very primitive contrivance, consisting of a small box-compass, around which were several turns of copper wire, coiled in a direction parallel to the meridian line of the card. The galvanometer was constantly improved, however, until it reached a high state of perfection in the hands of such pioneers as De Bois-Reymond and Sir William Thomson (as Lord Kelvin was then). Instruments of great delicacy were constructed, and some had as many as 30,000 turns of wire.

In 1821 Ampère further perfected the galvanometer by inventing the double or astatic needle, which he thus describes:

> "When a magnetic needle is withdrawn from the directive action of the earth, it acts itself, by the action of a voltaic conductor, in a

PLATE IV

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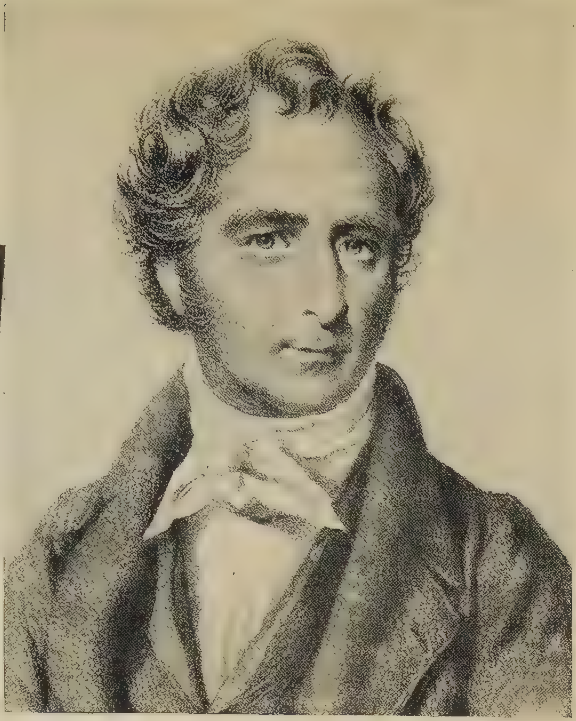
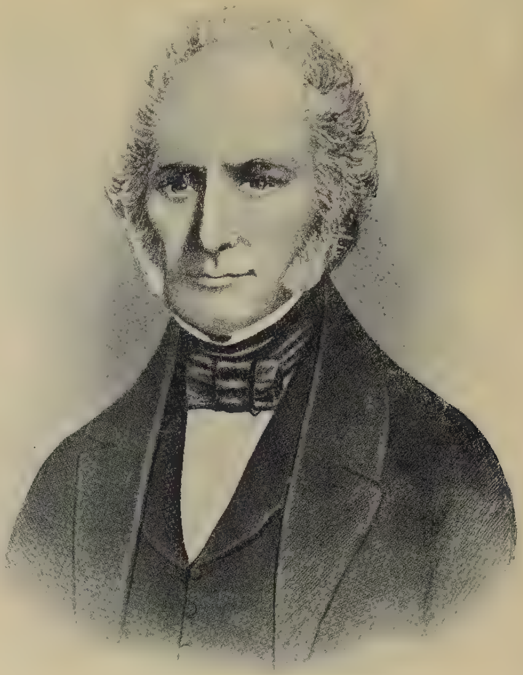


DOMINIC FRANÇOIS ARAGO
(1786-1853)



WILLIAM STURGEON
(1783-1850)

direction that makes a right angle with the direction of the conductor, and it has its south pole to the left of the current against which it is placed. Thus, if Oersted, in the experiments that he published in 1820, only obtained deviations of the needle that were less than a right angle, on placing it above or below a conducting wire parallel to its direction, it was solely because the needle that he subjected to the action of the current was not withdrawn from that of the earth, and took consequently an intermediate position between the directions that the two forces tended to give it.

" There are several means of withdrawing a magnetic needle from the earth's action. A very simple one consists of attaching to a stout brass wire, which has its upper part curved and fitted with a steel point in suspension, two magnetic needles of equal strength, in such a manner that their poles are in opposite directions, so that the directive force of the earth upon one is destroyed by the action in the opposite direction that it exercises on the other. The needles are so arranged that the lower one is just below the conducting wires and the upper one close above them. On sending a current through the convolutions the needles turn, until they take a direction at right angles to the conducting wire." [1]

In other words, Ampère produced a galvanometer in which the needle was freed from the influence of terrestrial magnetism—and thus became more sensitive to electric currents—by suspending the needle so that terrestrial magnetism acted perpendicularly to it and therefore had no directive force upon it. It only remains to remark that the credit of his discovery has often been erroneously attributed to Nobili and that Professor Cummings, in a paper (read 2nd April, 1821) before the Cambridge Philosophical Society, described a near approach to the astatic needle, but his effect was obtained by neutralizing terrestrial magnetism with a small magnetized needle placed below the galvanometer needle.

III

An announcement of considerable importance to electricity in general and wireless in particular was made in 1825. This was the discovery, by Sturgeon, of the electro-magnet, an appliance that is the basis of nearly all the technical applications of electricity. The electro-magnet is also of the greatest service to the physicist, and many of Faraday's brilliant discoveries were made by its aid.

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[1] *Annales de Chimie et de Physique*, vol. xviii, p. 320.

William Sturgeon (*b*, Plate IV) was born on 22nd May, 1783, at Whittington, near Kirkby Lonsdale, Lancashire. His father, John, an ingenious but idle shoemaker who neglected his family to poach fish and rear gamecocks, came from Dumfries. In 1796 he married Betsy Adcock, daughter of a small shopkeeper at Whittington.

William had little or no education, and was apprenticed to a cobbler at Old Hutton, who starved and ill-used him. As he saw no hope of advancing in his trade he joined (in 1802) the Westmorland militia. Two years later, at the age of 21, he enlisted as a private in the Royal Artillery, with the 2nd Battalion of which he served 20 years. He went out with them to Newfoundland, and a terrific thunderstorm caused him to turn his attention to natural science, particularly electricity and magnetism.

In order that he might understand what had been written on the subject, he educated himself in barracks and, with the help of a friendly sergeant who lent him books, studied mathematics, Latin, and Greek. When he returned to Woolwich his models and electrical apparatus attracted some considerable attention, and we are told that the cadets of the Royal Military Academy "used to swarm on the barrack field to get shocks from his exploring kites".

Sturgeon left the Army on 1st October, 1820, when 37 years of age, his commanding officer testifying that his conduct had been "altogether unimpeachable". Curiously enough, in spite of his intelligence, he never rose above the rank of gunner. On discharge, as his pension was only one shilling per day, he resumed his old trade of shoemaker, and during his spare time constructed scientific apparatus and lectured to schools. He produced, in a modified form, Ampère's rotating cylinders, which he described in the *Philosophical Magazine* for 1823, and in the following year he contributed to the same journal four able papers on thermo-electricity. Through the influence of several scientific men, with whom his work had brought him into contact, he was appointed Lecturer in Natural Science and Philosophy at the East India Company's Royal Military College.

In November, 1823, Sturgeon noticed that when a core of soft iron was placed within an electrical coil, the iron immediately became a strong magnet, and that the instant the current was broken the magnetism disappeared (Fig. 6). In May, 1825, he presented to the Society of Arts his improved apparatus for electro-magnetic experiments, including his first soft iron electro-magnet, but unfortunately these early historic relics have since disappeared.

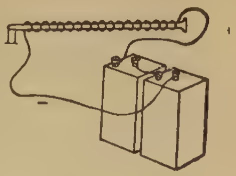
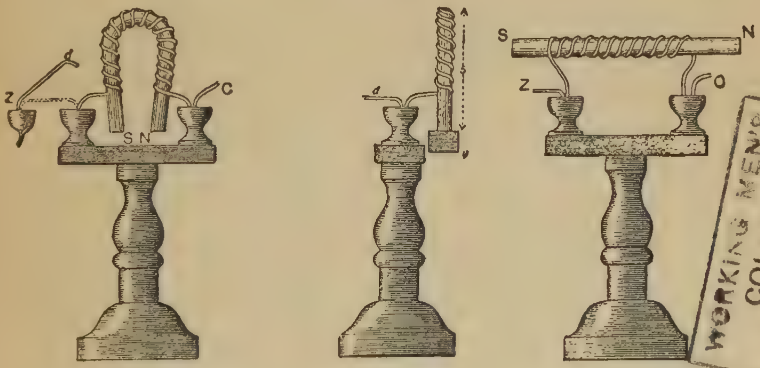


FIG. 6

An electric current passing through a wire wound around an iron core, causes the latter to become temporarily magnetized.

Sturgeon's original electro-magnet consisted of an iron bar ½ in. in diameter and 12 in. in length. This was bent in the form of a horse-shoe and coated with an insulating varnish (Fig. 7). Eighteen turns of bare copper wire, each separated from the other, encircled the horse-shoe and were connected to a voltaic battery with an area of 130 sq. in.[1] Although this crude electro-magnet weighed only 7 oz., it was capable of supporting a weight of 9 lb.—quite a remarkable performance in those early days.



A. Front view. B. Side view. (Horse-shoe type.) C. Bar type.

FIG. 7—STURGEON'S ORIGINAL ELECTRO-MAGNETS

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Sturgeon was awarded the Society's silver medal and a premium of thirty guineas on his agreeing not to patent the electro-magnet.

In 1826 Sturgeon experimented with the firing of gunpowder by electric discharges. In 1830 he made the important discovery of the now well-known process of amalgamating the zinc plate of a voltaic cell with a film of mercury, thus effecting a considerable economy in zinc waste when the cell was not in use. Shortly after this he experimented with the phenomenon of the magnetism of rotation, discovered by Arago, and came to the conclusion that the results were due to a disturbance of the " electric fluid " by magnetic action—a kind of reaction to that taking place in electro-magnetism. The actual cause of the phenomenon was brilliantly explained by Michael Faraday in 1831 in his researches on magneto-electric induction. In 1832 Sturgeon constructed an " electro-magnetic rotary engine ", the first contrivance, Joule assures us, by means of which any considerable mechanical force was developed by the electric current.

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[1] Society of Arts, *Transactions*, 1825, vol. xliii, pp. 38–52.

In the same year an exhibition of models and inventions was held at the Adelaide Gallery[1] in the Strand, and Sturgeon was appointed to the lecturing staff, but the appointment was only of short duration, for the Gallery did not achieve any degree of popularity and was closed. In 1836 he established a new monthly publication, *The Annals of Electricity*, the first journal to be solely devoted to the subject. This continued until 1843, and it is interesting to note that it was to this publication that James Prescot Joule, a Manchester brewer, contributed the results of his own researches in electro-magnetism. In passing it may also be mentioned that Joule succeeded in making an electro-magnet, of which the core was an iron tube, weighing only 15 lb. but capable of supporting nearly 1 ton.

In 1837 Sturgeon invented his electro-magnetic coil machine for giving shocks. About this time, too, he discovered an effective means of preventing the frequent fracture of Leyden jars by heavy electric discharges.

In 1840, at the age of 57, he went to Manchester to act as superintendent of the Royal Victoria Gallery of Practical Science. This was an institution intended to increase popular interest in science, and was a pioneer of the present-day technical schools. But, as was the case of the Adelaide Gallery and the Royal Polytechnic in London, the movement was in advance of its time, and after four years the Gallery was closed. Sturgeon then lectured in the towns around Manchester, carrying his apparatus about in a cart. In this manner, although he added to his reputation, he only managed to eke out a bare livelihood.

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[1] The site of this building is now occupied by Gatti's restaurant.

The last five years of Sturgeon's life were spent in great penury, and he keenly felt the pinch of poverty. Influential friends, including the Bishop of Manchester, succeeded in obtaining for him a grant of £200 from the Civil List and (in 1849) a pension of £50 per annum. In 1847 his health compelled him to remove for a time to Kirkby Lonsdale, where he continued his observations on atmospheric electricity. He later returned to Manchester, however, and died at Prestwich on the 4th December, 1850. He was buried in the churchyard there, and a marble tablet was subsequently erected to his memory in Kirkby Lonsdale church.

Sturgeon is described as having been a tall, well-built man, with a high forehead and strongly marked features. He had an animated manner and a lucid and vigorous literary style. Jacobi, of St. Petersburg, has claimed him as co-discoverer with Oersted of the principle of the electro-magnetic engine. Certainly Sturgeon was the first constructor of this apparatus, and there seems to be no doubt that he clearly perceived the possibilities of the electro-magnet as a source of mechanical power. He was the first to discover and perfect an apparatus for what was then termed "throwing opposing currents in one direction"—a contrivance now known as the commutator. He foresaw the possibilities of electric light, and at one of his lectures (in 1849) exhibited an electric light, the current for which was obtained from a 100-cell galvanic battery. "I quite anticipate," he prophesied, "that the electric light will supersede gas for public, whatever it may do for private, purposes."

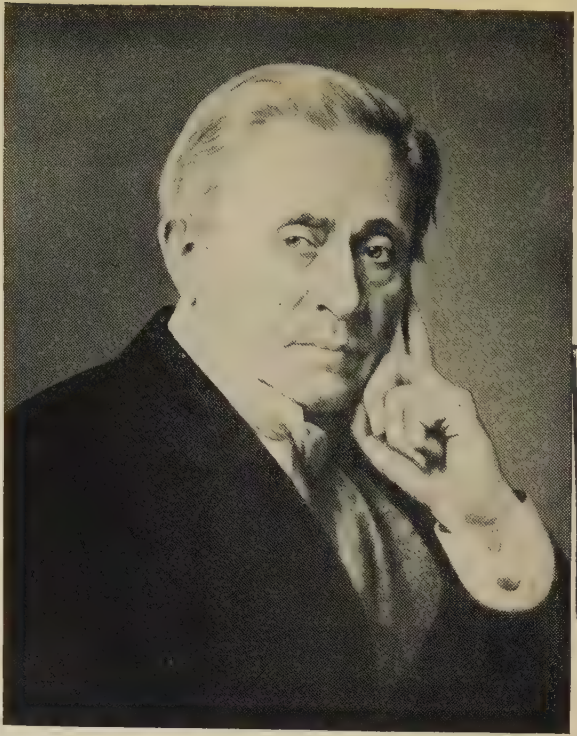
Sturgeon was constantly endeavouring to simplify and cheapen his apparatus so that his discoveries might be more readily available for practical purposes. It is interesting to learn that in his day a Grove's battery cost £7 and a Daniel cell £6, both of which Sturgeon superseded with his own battery costing £3 10s.

IV

In recent years Sturgeon's work has often been overlooked, credit for the discovery of the electro-magnet generally being claimed for Joseph Henry, in America. In this connection it is interesting to find that J. P. Joule said that to Sturgeon " is undoubtedly due the credit of being the original discoverer, he having constructed electric-magnets in soft iron, both in the straight and horse-shoe shape, as early as 1832 ". What Henry did was to greatly improve Sturgeon's primitive device, and, as we shall shortly learn, it was chiefly his researches, and the remarkable discoveries resulting therefrom, that placed the science of electro-magnetism on a sound basis. Many of Henry's discoveries and inventions, and much of the electrical apparatus that he developed, find their application in devices used in wireless telegraphy and telephony.

Joseph Henry (*a*, Plate V), born on 17th December, 1797, at Albany, New York, was of Scotch descent. Little is known of his father, who died when the boy was about nine years old. His mother was a woman of refinement, " delicate in form and feature, very beautiful, and deeply devotional ". At the age of seven Joseph went to live with his maternal grandmother at the little country village of Galway, in Saratoga County, and near to where the city of Schenectady now is. Here he attended the country school, and three years later was placed in Broderick's country store, where he worked for five years, his employer permitting him to attend school in the afternoons. He was said to be " a handsome, slender lad, of delicate complexion, vivacious manners, and a great favourite ". He was fond of reading, especially books of fiction, and, with a highly imaginative mind, loved to amuse the young villagers by relating to them the stories he had read. Sitting on a barrel in the evening, he would discourse to all who would listen of the wonders he had found in his reading. Strangely enough, it was poetry and the drama that engaged his interest over all else, and we can imagine the effect his effusions must have had upon the Galway farmers sitting about on the counter and boxes of Broderick's store while Henry's vision and imagination gave vent to themselves—the

PLATE V



JOSEPH HENRY
(1797-1878)

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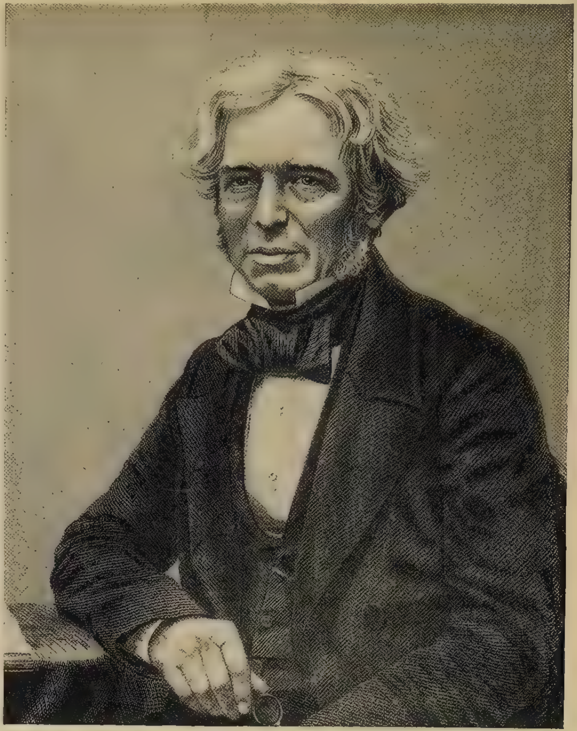

MICHAEL FARADAY
(1791-1867)

budding of that great vision that must accompany every successful worker in the field of science.

When about 14 years of age, he served a brief apprenticeship to a silversmith in Albany, and although the work was not altogether congenial, it was of value in enabling him to acquire the manual dexterity that was so useful to him in after life. At this period his great ambition was to become an actor, and he took some part in local amateur theatricals, organizing a dramatic club among the boys, writing a play, and staging it before the little community. His interest in the theatre was of short duration, however, and he turned his attention to scientific study. It is related that his interest in science was aroused by finding a book—*Gregory's Lectures on Experimental Philosophy, Astronomy, and Chemistry*—that a visitor had left upon his mother's table. The book commenced by asking such questions as: "Why does a stone thrown into the air stop at a certain distance and then return? Why does smoke and flame always mount upwards? What is reflection of light?" The influence of this book upon Henry's life is indicated by the following entry made in his own handwriting:

> "The book, although by no means a profound work, has, under Providence, exerted a remarkable influence upon my life. It accidentally fell into my hands when I was about 16 years old and was the first book I ever read with attention. It opened to me a new world of thought and enjoyment, invested things before almost unnoticed with the highest interest, fixed my mind on the study of nature, and caused me to resolve at the time of reading it that I would immediately commence to devote my life to the acquisition of knowledge."

This resolution proved no light undertaking. His mother's means were too limited to permit of his constant attendance at school, so he began by taking evening lessons from two of the Professors in the Albany Academy, making a special study of geometry and mechanics. He learned the elements of grammar from a travelling teacher, and having mastered this subject, travelled about the country and earned sufficient money to enter the Albany Academy. By teaching at intervals and practising strict economy, he was able to complete his studies at the Academy, from which he graduated at the age of 18, obtaining a position as private tutor. As this work required only his morning hours, he was able to devote his afternoons to further mathematical and physical studies.

Shortly after this he became an assistant to Dr. Beck, Professor of Chemistry at the Albany Academy, and immediately showed his ability as an experimentalist. He now had but little time for his own experiments, for his teaching duties claimed his attention for seven hours each day. He found it necessary to commence work early in the day, and some of his classes were held at 6 a.m. Half his time was occupied in guiding large classes of boys through the elements of arithmetic, and we may well imagine that on many such occasions his thoughts were elsewhere. As his salary at this time was only £16 a term, it will be readily seen that his resources for the purchase of apparatus and equipment were limited. Meanwhile he took every means to earn money to pay for his further tuition. During the holidays he taught in a district school for 10s. a week and tutored the sons of the Patron of Albany, Van Rensselaer.

By some chance, not explained, Henry had already come into contact with Amos Eaton, the greatest teacher of his time, just before he was appointed first Director of the Rensselaer School at Troy. Eaton was then lecturing at the Troy and Albany Lyceums on various branches of science, particularly on geology, the science of his choice. In 1820, when Henry was 21 years of age, Eaton was commissioned by General Stephen Van Rensselaer to execute an agricultural and geological survey of Rensselaer and Albany counties, probably the first survey of this character ever undertaken. Eaton took Henry along as one of his field assistants, and so the young man became a geologist. The geological specimens collected by Eaton and Henry on this earliest of all geological surveys are still preserved in the New York State Museum.

Upon his return in 1826, Henry was elected Professor of Mathematics in the Albany Academy, and here he at once equipped a laboratory in a " little lower room ", as he called it, where he began to experiment with galvanic batteries and the transmission of the galvanic current. He was convinced that by the medium of this current mechanical power could be transmitted to a distance, and his subsequent researches in this connection made him a worthy contemporary of the great Faraday. Unlike Faraday, however, Henry was a keen mathematician. Although working in the same field but with different methods of approach, these two brilliant men had much in common, and it is pleasing to learn that they became firm friends.

V

Some account of Sturgeon's discovery of the electro-magnet reached Henry in America, and this caused him to consider the subject more fully. He had already had his attention drawn to electro-magnets by Schweigger's galvanometer, which he had greatly improved by insulating the conducting wire itself instead of the rod to be magnetized and by covering the whole surface of the iron with a series of coils in close contact.

In June, 1828, he exhibited at the Albany Institute an electro-magnet—a piece of soft iron bent in the form of a horse-shoe and closely wound with silk-covered copper wire one-thirtieth of an inch in diameter. By using this form of wire—which he persuaded the young ladies of Albany to cover for him—instead of varnishing the iron bar and using bare wire as Sturgeon had done, he obtained a compact coil containing a considerably greater number of turns of wire. Each turn was more nearly at right angles to the magnetic axis of the bar, and the whole arrangement gave a lifting power much greater than that of any of Sturgeon's magnets. It may be noted that this was the first recorded occasion on which individual copper wires were insulated with a covering of silk. The method has since been continuously used, and is found to-day in every application of the electro-magnet.

In March, 1829, Henry exhibited at the Albany Institute a larger magnet of a similar type. A piece of iron of quarter-inch diameter was bent into the usual horse-shoe form and tightly wound with 35 ft. of silk-covered wire in some 400 turns, each layer being further insulated by silk ribbon placed between.

> " In the arrangement of Arago and Sturgeon ", said Henry, " the several turns of wire were not precisely at right angles to the axis of the rod, as they should be to produce the effect required by the theory, but slightly oblique, and therefore each tended to develop a separate

magnetism not coincident with the axis of the bar. But in winding the wire over itself, the obliquity of the several turns compensated each other and the resultant action was at the required right angles. The arrangement, then, introduced by myself was superior to those of Arago and Sturgeon, first in the greater multiplicity of turns of wire, and, second, in the better application of these turns to the development of magnetism.

"The maximum effect, however, with this arrangement and a single battery was not yet obtained. After a certain length of wire had been coiled upon the iron, the power diminished with a further increase of the number of turns. This was due to the increased resistance that the longer wire offered to the conduction of electricity. Two methods of improvement, therefore, suggested themselves. The first consisted, not in increasing the length of the coil, but in using a number of separate coils in the same piece of iron. By this arrangement the resistance to the conduction of the electricity was diminished, and a greater quantity made to circulate around the iron from the same battery. The second method of producing a similar result consisted in increasing the number of elements of the battery, or, in other words, the projectile force of the electricity, which enabled it to pass through an increased number of turns of wire and thus to develop the maximum power of the iron." [1]

Henry demonstrated that a horse-shoe of half-inch iron, 10 in. in length, and wound with 30 ft. of fine copper wire, actuated by current from only $2\frac{1}{2}$ sq. in. zinc, would hold a weight of 14 lb. When he wound on it a second wire of 30 ft. it lifted 28 lb. (see Plate VI).

"These experiments conclusively prove", he wrote, "that a great development of magnetism could be effected by a very small galvanic pair, and also that the power of the coil was materially increased by multiplying the number of wires, without increasing the length of each. The multiplication of the wires increases the power in two ways, first by conducting a greater quantity of galvanism, and secondly by giving it a more proper direction; for since the action of a galvanic current is directly at right angles to the axis of a magnetic needle, by using several shorter wires we can wind one on each inch of the length of the bar to be magnetized, so that the magnetism of each inch will be developed by a separate wire. In this way the action of each particular coil becomes directed very nearly at right angles to the axis of the bar and consequently the effect is the greatest possible. This principle is of much greater importance when large bars are used. The advantages of a greater conducting power from using several wires might, in a less degree, be obtained by substituting for them one large wire of equal sectional area; but in this case the obliquity of the spiral would be much greater and consequently the magnetic action less." [1]

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[1] *Smithsonian Report*, 1857, p. 102.

In the following year (1830) Henry constructed magnets that performed even more extraordinary feats than their predecessors. Of a 2-in. square iron bar, 20 in. in length, wound with 540 ft. of copper wire in nine coils of 60 ft. each, Henry wrote :

> " My new magnet weighs 21 lb. and lifts more than 35 times its own weight. It is probably therefore the most powerful magnet ever constructed."

In winding this magnet several strands of wire had been left projecting, so that numerous combinations could be obtained by uniting the different ends. When one from each leg was united, forming a circuit of 120 ft. of wire, the magnet had a lifting power of 60 lb. The same two wires when connected to form double circuits of 60 ft. each produced a lifting power of 200 lb. Four wires used in a similar manner gave 500 lb. Six wires in three pairs, forming three 180-ft. circuits, would lift only 290 lb., while the same wires separately connected gave 570 lb., or nearly double. With all nine wires joined in parallel the magnet gave its maximum power—735 lb.

In 1832 Henry was appointed Professor of Natural Philosophy in the College of New Jersey, at Princeton. Here he continued his researches and made at least two larger magnets. One, weighing 59½ lb. and capable of lifting 2,063 lb., was made for Yale University, and another, made in 1833, weighed 100 lb. and supported 3,500 lb. It is amusing to find that in his experiments with these magnets Henry liked to startle his pupils by suddenly cutting off the supply of current to one of his magnets, causing it momentarily to drop its load ; then instantly switching on the current again, he caused it to seize the load before it had fallen beyond the sphere of attraction. In other respects also he was not at all the typical inventor as generally depicted in popular fiction. One of his pupils at Princeton wrote of him :

> " His erect and noble form, firmly and gracefully poised, would have afforded to an artist an ideal model for an Apollo. The joy of

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[1] Silliman's *American Journal of Science*, 1831, vol. xix, p. 402.

conflict and of triumph beamed from his countenance—a conflict in which, for years, he had struggled with the phantoms that guard the hidden treasures of nature, and had ever been victorious. And above, surmounting all, infinite charity and gentleness—like the charity and gentleness of a loving mother for her erring children."

A man of great humility and unselfishness, he might have amassed great wealth if he had been willing to patent his inventions, but he declined to do so, because, he said, " I did not then consider it compatible with the dignity of science to confine the benefits that might be derived from it to the exclusive use of an individual ". Lest he might seem to cast a reproach on those who had patented their discoveries, he added : " In this, perhaps, I was too fastidious ".

VI

Ampère in 1820 had made the suggestion that " by sending a galvanic current through long wires connecting two distant stations, the deflections of enclosed magnetic needles would constitute very simple and efficient signals for an instantaneous telegraph ". But in 1825 Barlow, the eminent English physicist, tested Ampère's idea and found that the introduction of only 200 ft. of wire made such a reduction in the effect as to convince him of the impracticability of the scheme.

Henry attacked this problem in 1830–1, and found that with his " intensity magnet " supplied with current from an " intensity battery "[1] he could produce an undiminished effect with even 1,000 ft. of wire interposed. He then developed in a thoroughly scientific manner the relation of what he called the " intensity magnet " to the " intensity battery ", and the " quantity magnet " to the " quantity battery ". The intensity magnet was one of many turns of wire, and the intensity battery one with many cells connected in series. He thus made the electro-magnet capable of use in transmitting to some distance, and was the first to magnetize a piece of iron at a distance and to demonstrate thereby the possibility of the use of the electro-magnet for telegraphy. Describing his experiments in this connection he wrote :

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[1] His intensity battery was composed of a number of flat copper sheaths, each with a zinc plate inside.

> "Sometime during 1831, I arranged around one of the upper rooms of the Albany Academy a wire of more than a mile in length, through which I was enabled to make signals by sounding a bell. The mechanical arrangement for effecting this object was simply a steel bar, permanently magnetized, of about ten inches in length, supported on a pivot and placed with its north end between the two arms of a horse-shoe magnet. When the latter was excited by the current, the end of the bar thus placed was attracted by one arm of the horse-shoe and repelled by the other, and was thus caused to move in a horizontal plane and its further end to strike a bell suitably adjusted."

In this discovery, the first sounding electro-magnetic telegraph, Henry had in his hands the principle that subsequently made possible the Morse telegraph. Amazing to relate, he refused to patent it, for reasons already given. Ten years after Henry discovered the principle, Morse patented his first telegraph, and obtained a grant from Congress in order that he might continue his work. "The principles I had developed", Henry modestly wrote, "rendered Morse's instruments effective at a distance."

An account of these experiments reached Sturgeon, and it is interesting to learn that he said: "Henry has been enabled to produce a magnetic force that totally eclipses every other in the annals of magnetism, and no parallel is to be found since the miraculous suspension of the celebrated Oriental impostor in his iron coffin."

It may be remarked in passing that at the time of Henry's researches (1828–31) Barlow had declared that there could be no electric telegraph to a long distance. In speaking of the electro-magnet, Wheatstone, the originator of the needle telegraph system, said, as late as 1837, "It would not act and could not act as a telegraph, because sufficient attractive power could not be imparted to an electro-magnet interposed in a long circuit". It was evident that Wheatstone was not familiar with what Henry had demonstrated six years earlier.

VII

Continuing unknowingly to explore the fundamental principles of wireless, Henry next discovered (in 1832) induction, by which a current of electricity, passing through one coil of wire, induces another current in a second wire near by but not connected to the first coil.

> "In extending these researches," he wrote, "a remarkable result was obtained. It would appear that a single spark is sufficient to disturb perceptibly the electricity of space throughout at least a cube of 400,000 ft. of capacity, and . . . it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from flint and steel in the case of light."

"Comparable it is indeed," Sir Oliver Lodge has commented, "for we now know it to be the selfsame process."

Henry's greatest discovery was that electricity could be produced from magnetism. This was a discovery that Henry truly stated would certainly form "a new era in the history of electricity and magnetism". Telegraphic communication did not exist between England and America at that time, so that months, sometimes even years, elapsed before scientific discoveries in one country were made known in the other. Therefore, it does not detract in any degree from Henry's credit that Faraday in England had already anticipated his discovery by a few months.

Professor J. A. Fleming, writing in 1892, stated that "Henry's claim to be an independent discoverer of the fundamental effect of electro-magnetic induction is not now disputed", and goes on to say that "in the July number of Silliman's *Journal of Science* for 1832, Joseph Henry, then a young teacher in the Albany Academy, gave an account of the manner in which he had independently, and before receiving an account of Faraday's work (performed in the previous autumn), elicited from his own great electro-magnet an induced current by wrapping around the soft iron armature certain coils of insulated wire". Upon making and breaking the circuit of his electro-magnet, a current of electricity was induced in the coils surrounding the armature. "This simple experiment", Fleming says, "disclosed for the first time in history a method of obtaining from magnetism a current of electricity."

Henry was often unknowingly handling the forces that to-day make wireless possible. He showed, for instance, how to change high-tension current into low-tension current, or the converse, low-tension current into high tension, a discovery that is utilized in every electric transformer. Then again he demonstrated how the current induced in the secondary of two of his coils could be varied or regulated by changing the relation in space of the coils. Upon this is founded the " variometer " now used in nearly all radio applications. An even more remarkable instance was his discovery of what he called the " extra spark ". " A wire coiled into a helix", he stated, " gives a more intense spark than the same wire uncoiled. A ribbon of copper coiled into a spiral gives a more intense spark than any other arrangement yet tried." Without knowing it, Henry was again doing pioneer work in wireless research, for his " flat spiral " is in use to-day in wireless stations under the name of " oscillation transformer ".

He noticed the screening effect of a solid metal sheet interposed between the primary and secondary coils and showed how this screening effect could be controlled and eliminated. He even discovered the oscillatory nature of the discharge of a Leyden jar. Having made a galvanometer out of a darning needle and connected it up to a Leyden jar, he noticed that although the needle was magnetized on each occasion it was not always magnetized in the same manner. Sometimes it pointed north and at other times it pointed south. " The phenomena require us to admit ", he said (in 1842), " the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until equilibrium is obtained." Here again Henry was handling forces that make possible wireless of to-day, for he had discovered the high-frequency oscillations now obtained with condensers in place of the Leyden jar.

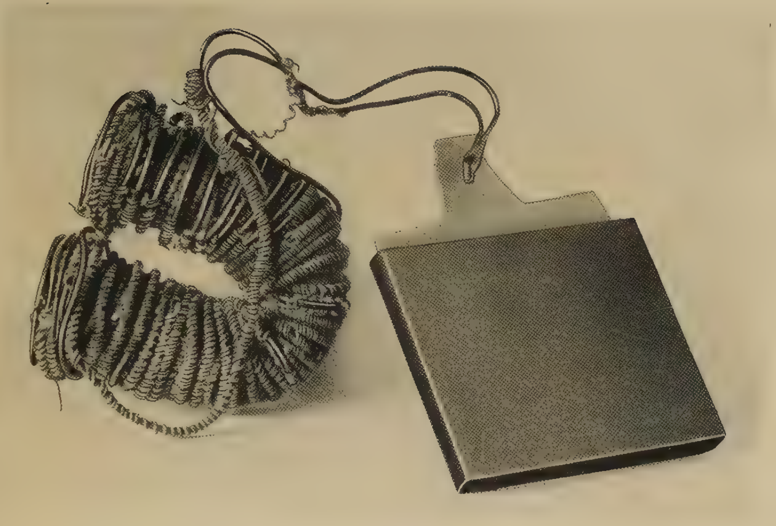
He realized the fact that there was considerable stress between the tin-foil and the knob of the jar, and that at the first discharge more current rushes from one to the other than was necessary to give rise to a neutral state. He realized, too, that some of the charges rushed backwards and forwards tens of thousands of times in a second until the jar became neutralized. He also showed that the discharge of a Leyden jar travels largely over the surface of a conductor, rather than through its interior, and that Ohm's law does not exactly apply in such a case.

Henry's experiments with so-called " ordinary " or frictional electricity obtained from a charged Leyden jar demonstrated that the discharge of a Leyden jar would produce " electricity in motion " and magnetic effects similar to those produced by the current from his galvanic batteries. Thus was established the identity of electricity in motion or " electric current ", whatever the source from which it was produced, an achievement that has been compared with Franklin's identification of lightning and electricity. He also studied the effect of lightning induction on telegraph wires, and suggested that its destructive effects could be diminished by erecting on the supporting poles a grounded metallic wire in close proximity to, but not in contact with, the telegraph wire.

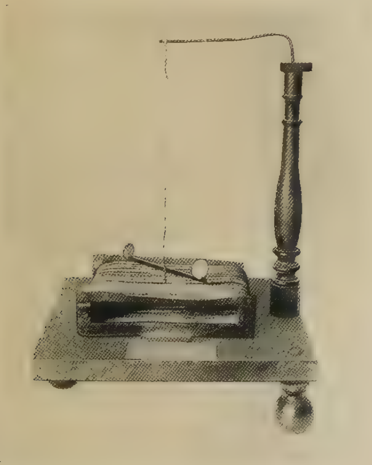
Henry invented the so-called electric relay, by which a relatively feeble current operated an electro-magnet that in turn controlled the local circuit of a more powerful magnet. This invention is not only used as the basis of magnetic amplifiers in wireless, but also has many other applications in telegraphy and electrical engineering. For instance, it is used in the operation at a distance of switches and signals, in the electric tramcar and the electric elevator. The entire modern method of electrical control, known as " remote control ", is but a natural extension of Henry's relay system.

Practically all of Henry's remarkable researches and original contributions to science were made while he was a Professor at Albany Academy and at Princeton College. In 1846 he was called to accept the position of first Secretary of the Smithsonian Institution at Washington. This institution was founded to give effect to the legacy of James Smithson, of England, who, in a will executed in 1828, devoted his patrimony to found at Washington an establishment for " the increase and diffusion of knowledge among men ". Whatever success this Institution has achieved is largely based upon the practical wisdom, perseverance, and genius of Henry, who devoted the remainder of his life to its upbuilding.

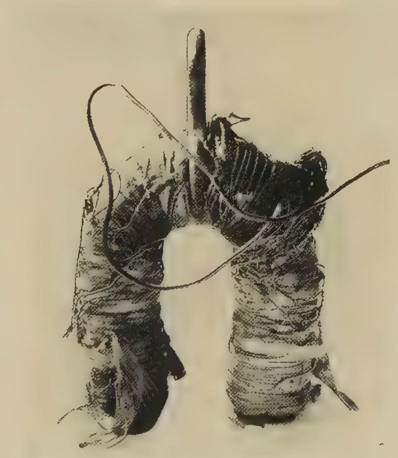
In 1837 Henry first visited Europe and became personally acquainted with its principal men of science, among them the illustrious Faraday. These two men not only had no disputes as to their contributions to science, but such records as have been left clearly show that each held the other in the



ONE OF HENRY'S ELECTRO-MAGNETS



HENRY'S GALVANOMETER



ANOTHER OF HENRY'S LARGE MAGNETS

highest esteem, and had nothing but mutual regard and kindly feeling. In fact, Faraday often spoke of Henry in terms of hearty admiration, and Henry apparently loved to dwell on the happy hours that he spent in Faraday's society upon the occasion of his visit to London. Both were much alike in their simplicity of character, genuineness, freedom from affectation, and in their loving devotion to scientific research.

Although we are here concerned only with Henry's electrical discoveries, it may perhaps be mentioned that he made notable researches in other scientific fields. He studied sunspots by a thermo-telescope of his own invention, and discovered that they were cooler than the rest of the sun's surface. He made notable discoveries in the field of acoustics and examined the obscure phenomena of phosphorescence. He investigated the cohesion of liquids, demonstrating the fallacy of existing views by showing that the cohesion in liquids was actually of the same order as that in solids. He was the first to apply the telegraph, then in its infancy, to meteorological work, and to make weather forecasts embracing a continent. During the last 25 years of his life he was a member of the American Lighthouse Board—for many years he was its presiding officer—and it was due to his work that one of the most serviceable systems of fog-signals was produced.

Henry died at Washington on 13th May, 1878, and although he lived long enough to be hailed as a genius and a prophet, he never saw the splendid results of his pioneer experiments. Both Hertz and Morse took up his work, the latter developing the telegraph and later signalling without wires by conduction. Hertz, as we shall show later, studied Henry's "extra spark" and also continued Henry's work in the investigation of the oscillating nature of condenser discharges.

Henry's name is perpetuated in the "henry", the unit of inductance, in accordance with the custom of associating the names of eminent discoverers with electrical units. For example, the name of Volta, who invented the voltaic pile, the first electric battery, is signalized by the "volt", the common unit of electric pressure. Ampère's name has been given to the unit rate of electric flow. The unit of electrical resistance is named after Ohm, who explained the relation between electric pressure, current, and resistance. The name of "farad" perpetuates the honour of the great Faraday. The unit of electric inductance was first named the "henry" at the International Electrical Congress held in Chicago in 1893, and was unanimously adopted by the delegates, representing all important foreign countries.

CHAPTER IV

MICHAEL FARADAY, FOUNDER OF ELECTRICAL SCIENCE

THE work of Oersted, Ampère, and Arago had a marked effect on scientific progress in general and in researches into electricity and magnetism in particular. What was of even greater importance is the fact that it prepared the way for Henry's discoveries, as already described, and for those of Faraday, in whose fertile brain originated many of the modern applications of electricity. As a pioneer of wireless, Faraday claims our notice on many grounds, not the least of which is that the wireless waves may be traced back, if not to his experiments, at least to his ideas.

Michael Faraday (*b*, Plate V), the son of a working blacksmith who came south from Yorkshire, was born at Newington Butts, London, on 22nd September, 1791. After a lifetime of brilliant research and experiment in Chemistry and Electricity, which placed him amongst the most distinguished scientists of the last century, he died at Hampton Court on the 25th August, 1867.

Of Michael's early days we know little, beyond the fact that these were hard times for working-class families. The Napoleonic wars were still impoverishing Europe and food was scarce and the cost of living high, so that his father, hard-working and deeply religious though he was, found it difficult to earn enough to feed his four growing children. Faraday himself has told us that his mother gave him a quartern loaf at the beginning of each week and that he had to make it last the week. When the boy was five years of age the family moved to Jacob's Well Mews, off Charles Street, Manchester Square, where they had rooms over a coachhouse. It was in these humble circumstances that the greatest scientist of his day—subsequently loaded with honours by every scientific body in Europe—spent his early years, playing marbles with other boys in the roadway near his home. In these circumstances there could be little money for schooling.

We next hear of Michael when, at the age of 13, he started life as an errand-boy at a bookshop in Blandford Street, his duties being to deliver the newspapers early in the morning and to collect them again later in the day—for in those times newspapers were expensive luxuries purchased only by the very wealthy and hired for a few hours by the majority. His master Riebeau was so satisfied with his " faithful service " that in the following year (7th October, 1805) he took him as an apprentice, without premium, to the trade of bookbinding. It was from the books he bound that Faraday obtained his first knowledge of the principles of electrical science. He was not content to accept the statements he read, however, if he could test them by experiment; and during his leisure hours he constructed such apparatus as was within the capacity of his slender purse. He made numerous experiments with electrical machines of his own construction, attended scientific lectures, and made many friends among men of culture.

In 1812 a happy chance determined his future. One day a customer named Dance called at the shop about the binding of some books and found young Faraday deeply engrossed in the perusal of an article on electricity in an encyclopedia he was binding. Hearing of the young apprentice's industry, Mr. Dance—who was a member of the Royal Institution—presented him with tickets for admission to four chemical lectures of Sir Humphry Davy. We can imagine Faraday's delight on seeing and hearing the greatest chemist of the day. He not only attended the lectures—sitting " pen in hand and his eyes starting out of his head "—but took copious notes. These he later wrote out fully in a large notebook, expanding them where possible and illustrating them with carefully drawn diagrams.

By this time he had completed his term of apprenticeship and was working as a fully qualified journeyman bookbinder for another bookseller, Mr. de la Roche, who promised him an interest in the business if he would remain in his employ. Faraday tells us, however, that in his opinion " trade is vicious and selfish", while, on the other hand, "science makes its pursuers amiable and liberal". With this idea in his mind, and being without private means or influence, he conceived a bold plan. "My desire to escape from trade", he tells us, "induced me at last to take the bold step of writing to Sir Humphry Davy, expressing my wishes and a hope that if an opportunity came in his way he would favour my views. At the same time I sent the notes I had taken of his lectures."

It is not surprising that Davy was puzzled when he received this unusual request. "What am I to do?" he asked one of his colleagues at the Institution. "Do?" the other rejoined, "... why, put him to wash bottles. If he is good for anything he will do it directly; if he refuses he is good for nothing!" Faraday's enthusiasm was not to be given so great a test, however, although no one doubts that he would have washed the bottles, and washed them well, if this had been his task. One night, soon after this letter had been dispatched, there came a loud knocking at the door of Faraday's humble lodging. In the street was Davy's splendid carriage, and a liveried servant handed Faraday a note asking him to call on Sir Humphry next morning. This he did and Davy had a kindly talk to him, pointing out that science was a hard mistress who gave but scanty pecuniary rewards even for great discoveries. Faraday was not to be deterred, however, and the outcome of the interview was that a few months later he was appointed Sir Humphry's assistant at a salary of 25s. per week. In later years, when being congratulated on his discoveries, Sir Humphry Davy would say: "Yes, but my best discovery was Michael Faraday!"

Faraday soon assisted Davy in his lectures and in his experiments, which were sometimes of a perilous nature. In October, 1813, Davy went abroad to visit the universities and laboratories of Europe, Faraday accompanying him as valet and secretary. The tour, which lasted nearly two years and extended to Paris, Genoa, Florence, Rome, Naples, and Geneva, enabled Faraday to make the acquaintance of many of the leading scientists of the day, including Ampère.

In sharp contrast to Davy's kindness, it is remarkable that his wife behaved badly to Faraday, never allowing him to forget he was a menial and insisting on occasion that he should take his food with the grooms! This does not appear, however, to have perturbed Faraday, who had a beautiful character and a charm of manner that endeared him to all with whom he came in contact.

The travellers returned from their tour in April, 1815, and Faraday resumed his work as laboratory assistant at the Royal Institution, and the years that followed were full of unremitting toil. He extended his knowledge in all directions, assisting at lectures, reading in the library, conversing with Davy and other scientists, and continuously experimenting.

II

As we have already seen, it was in 1820 that Oersted had discovered the relationship existing between the electric current and magnetism. This discovery caused great interest throughout the scientific world and Faraday's attention was attracted by the subject. In the following year he wrote an account of all that was then known of electro-magnetism, having first performed the majority of the experiments he described.

He had no time to extend these experiments, however, for from 1821 to 1829 he was engaged in technical researches in connection with steel and glass manufacture. These were carried out for the Royal Institution, and despite the wealth of time and thought he expended on them, they did not lead to any results of commercial value. In the meantime he had discovered benzol and had shown how the gas chlorine could be liquefied. He had also reduced to the liquid state others of the so-called permanent gases, thus placing the ideas of the relation between the liquid and gaseous states on a sound basis, clearing the way for a correct dynamical theory of matter.

In 1825 the blacksmith's son and bookbinder's apprentice succeeded Sir Humphry Davy at the Royal Institution as Director of the laboratory that he had entered as a humble assistant. He then began the great work that will for ever remain a monument to his memory. Oersted had discovered the property of electricity to deflect a magnetic needle and Arago had discovered its corollary—the magnetizing power of an electric current. These discoveries convinced Faraday of the possibility of magnetism producing electricity. In one of his notebooks of this period he wrote a reminder for a future experiment to "change magnetism into electricity". Working along these lines, he reversed Oersted's experiment, and found (in 1831) that if a magnet be moved towards or from a coil of wire, a momentary electric current is induced in the wire (Fig. 8).

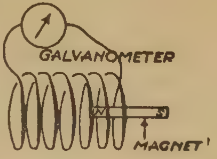


FIG. 8

Moving a magnet through a coil of wire produces a current.

By this discovery Faraday even more definitely connected the lodestone of the ancients with the current electricity of Volta. He showed that there is a close relationship between electricity, magnetism, and motion, and that electrified bodies in rapid motion produce magnetic fields around themselves. He also demonstrated that a magnet in motion has the power of creating currents of electricity in conductors that are close to it. These two discoveries are now in everyday use, and form the basic principle of the electric motor and the dynamo (Fig. 9).

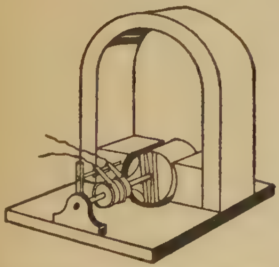


FIG. 9—SIMPLE FORM OF ALTERNATOR

Faraday had noticed that a current was induced only as long as the magnet was in motion, either approaching or receding from the wire. He realized that in order to obtain a continuous current the motion must also be continuous, and he devised a machine to effect this. He rotated a copper disc between the poles of a magnet and made a contact with it by conducting wires between the axle and the circumference. As each section of the wheel crossed the magnetic field a current was induced in the wire. In this machine will be recognized the first dynamo, the practical importance of which was that with it ordinary mechanical energy, such as is produced by a steam-engine, could be directly converted to electrical energy. Not only did the dynamo result from these pioneer experiments, but the transformer and the induction coil, to the subsequent perfecting of which we owe the present developments of wireless, X-rays, and many other forms of useful discoveries.

Ampère had already shown that every magnetic effect could be imitated by an electric circuit suitably adapted to the particular requirement. Following this line of thought, Faraday showed that it was possible to produce induced currents without the action of a permanent magnet, using instead the action of one electric circuit on another. He called this "Volta-electric" induction, as distinct from the "magneto-electric" induction obtained when a permanent magnet was used. He considered their identity of action and their results a very strong proof of Ampère's theory of magnetism. Twenty years later he showed that Volta-electric and magneto-electric induction are identical, and in doing so he threw considerable light on the relation of electricity to magnetism and the relation of both to light.

III

The value of Faraday's work as a pioneer of wireless is difficult to determine. His discoveries included induction, the transformer, and the dynamo. His work subsequently made possible the electric telegraph and the telephone, and the many applications of electricity and electro-magnetism that are to-day part of the great driving force of every civilized country. The fundamental principles of wireless are based on his discoveries, for waves of magnetic force, radiated from a transmitting station, encounter the wire of an aerial and, sweeping across it, induce in it minute electric currents. Faraday could not have had any idea of the use for communicating without wires that would be made of his discovery. His pioneer work was also of the utmost consequence to wireless in another direction, as being the means of leading that great mathematician, Clerk-Maxwell, to investigate electro-magnetism with brilliant results, as we shall read later.

In private life Faraday was a gentle and affectionate man, always willing to extend a helping hand to those endeavouring to climb the ladder of learning. "I am no discoverer," he once said, "but simply one of a vast crowd of workers scattered over the earth, who in the providence of God are invested with some proportion of the Divine afflatus. . . ." A charming man and a brilliant genius, whose work we cannot but pause to admire.

In closing this chapter on Faraday's work, reference may be made to one curious and mystifying incident. For some reason or other Faraday failed to appreciate Sturgeon's work in electro-magnetism. He always attributed the invention of the electro-magnet to Moll and to Henry, although both these pioneers stated that their work was based on the initial discovery made by Sturgeon. Joule, who entertained a high opinion of Sturgeon's work, stated that he had sifted to the utmost Sturgeon's claim to be the inventor of the electro-magnet and had found it to be valid. In spite of all these statements, Faraday would never recognize Sturgeon's work. This is all the more remarkable in the case of Faraday, who has been described as being "a good, almost saintly man".

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CHAPTER V

PIONEERS OF SIGNALLING WITHOUT WIRES BY CONDUCTION; SÖMMERING USES WATER IN PLACE OF WIRES; STEINHEIL AND THE "EARTH RETURN"; MORSE MAKES HISTORY; LINDSAY EXPERIMENTS WITH CONDUCTION IN SCOTLAND

EVERYONE knows that current electricity is obtained from batteries or cells, some types of which consist of a carbon and zinc, immersed in acid. The carbon and the zinc are each at a different potential, the carbon being the positive terminal and the zinc the negative terminal (Fig. 10). Because neither is able to do work separately it is said that a circuit must be completed and a current allowed to flow through the battery to enable an electric bell to be rung or other work performed. This was realized in the early days of electricity, and it was well understood that in order to produce the current the two wires connecting the battery to the objective must be kept apart.

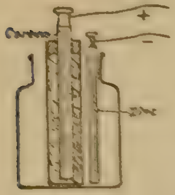

Fig. 10—A Leclanché cell.

Although practically all the earliest proposals for electric telegraphs based on static electricity relied on using only one wire, employing the earth itself as a return to complete the circuit, the true part it played in this respect was either unsuspected or misunderstood.[1] That it was also possible to complete the circuit of dynamic electricity through the earth appears to have first been discovered by Winkler, of Leipsic (on 28th July, 1746), when he discharged Leyden jars through an insulated wire laid along the bank of the River Pleiss, the waters of which formed the return half of the circuit.[2]

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[1] See, for example, Watson's experiments, Priestley's *History of Electricity* (1767), pp. 111–13.

[2] *Encyclopædia Britannica* (1810), p. 59, and Priestley's *History of Electricity*, p. 59.

Later in the same year he successfully transmitted over a distance of two miles, with the earth as a return circuit. It is interesting to note in passing that on this occasion Winkler insulated his wire with baked wood. Two years previously he had announced that "electricity could be transmitted to the end of the earth if a conducting body covered or insulated with silk be laid so far. . . ."[1]

Other subsequent instances in which the earth was similarly employed are numerous. For instance, in 1747, Dr. (afterwards Sir William) Watson in England appears to have been the first to improve upon this experiment by suggesting the use of the earth itself instead of water to complete a circuit. He transmitted an electric current over a single wire 2,800 ft. in length and followed this by transmitting over a distance of two miles, in each case using the earth as a return circuit.

In 1795 Salva, an eminent Spanish physicist and the inventor of the first electro-chemical telegraph, described how insulated wires might be laid under the oceans and the water used, instead of return wires, to complete the circuit. He also suggested using for wireless communication the theory, advanced by Bertolon, that earthquakes are caused by electricity moving from one point of the earth, charged with positive electricity, to another point charged negatively. Bearing this theory in mind, he suggested that "one does not even require a cable to send across the sea a signal arranged beforehand. One could, for example, arrange at Mallorea an area of earth charged with electricity, and at Alicante a similar space charged with the opposite electricity, with a wire going to, and dipping into, the sea. On leading another wire from the seashore to the electrified spot at Mallorea, the communication between two charged surfaces would be complete, for the electric fluid would traverse the sea, which is an excellent conductor, and indicate by a spark the desired signal".[2]

Salva's curious suggestion was not as impossible as it might seem at the first glance. For instance, telegraph operators are familiar with "bad earths", caused by the electrification of large areas of the earth's surface. J. Gott, when Superintendent of the Anglo-American Telegraph Company at St. Pierre, drew attention to the fact that the island was, perhaps, "better insulated than most places. Hundreds of yards from the station, if a wire be connected to earth, run some distance, and put to earth again with a telephone in circuit, the signals passing through the cables can be heard". There were two offices on the island, one operated on the Morse system with a powerful battery and the other equipped with very delicate instruments, a Thomson dead-beat mirror galvanometer and a Thomson siphon recorder. The former was found to be affected by earth currents to so serious an extent that the staff laid an insulated wire three miles in length and terminating in a metal plate placed in the sea, to be used in place of the ordinary earth. This effected an improvement, and it was noticed that some of the interruption had been caused by the Morse signals sent by the other office, and as a matter of fact the signals were automatically recorded on the tape when the recorder was in circuit between the ground at the Cable Office and the sea ground, three miles distant.

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[1] Winkler: *Thoughts on the Properties, Operations, and Causes of Electricity*, Leipsic (1744), p. 140.

[2] *On the Application of Electricity to Telegraphy*, read before the Academy of Sciences, Barcelona, 16th December, 1795.

The explanation of all this was that the potential of the ground at the two offices was alternately raised and lowered by the sending of the Morse signals, whilst the potential of the sea remained practically unaltered. The island was therefore acting in a similar manner to a huge Leyden jar, charged by every Morse signal and discharged through the short insulated wire. Each time the transmitting key was depressed the whole island was electrified, and the charge was detected and indicated by the delicate recorder. As a result of these observations, Gott stated it to be his opinion that "speaking through considerable distances of earth without wires is certainly possible with Bell's telephone, with a battery and Morse signals".[1]

II

On 27th February, 1803, Aldini sent a current from the West Mole of Calais harbour to Fort Rouge, through a wire supported on the masts of a boat, and made it return through 200 ft. of intervening water. About the same time, Basse made similar experiments, using the water in the moat around Hamel, the experiment being effective over a distance of 500 ft. Experiments were also made on the Weser, then with two wells 200 ft. apart, and later across a meadow 3,000 ft. in width.

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[1] *Journal*, Institute of Electrical Engineers, vol. vi, p. 523.

These experiments are very interesting because they constitute the first recorded transmissions of the electric current without wires. It must be pointed out, however, that they were not conducted in connection with any experiments in wireless telegraphy, but with a view to determining the speed at which the electric current travels.[1]

It was not until 6th June, 1811, that the eminent German scientist Sömmering (*a*, Plate VII), of Munich, who was experimenting with a form of telegraph, used water in place of wires to conduct the current for telegraphic purposes. He did this as the result of a suggestion made by his friend Baron Schilling, when the latter was inspecting his ingenious chemical telegraph. It was found that when the conducting wires were cut and the ends separated by an interval of water in wooden tubs, the current completed the circuit exactly as though the wires had not been cut. It was further found that the signals ceased when the water in the tubs was connected by a wire. As a matter of fact, had he been able to use a more delicate instrument for recording the signals, Sömmering would have noticed that a minute current did actually cross the water, even when both wires were introduced into the same tub. As two separate bodies of water are not often to be found together in natural conditions, Sömmering came to believe that his suggested method was impractical, although he and Schilling succeeded in performing other experiments, first across a canal off the River Isar and then along the river itself.

Although Sömmering's system had thus only a brief life, it was the earliest practical method proposed for wireless communication, and as such deserves our special notice. Sömmering, a distinguished anatomist and physiologist, was born at Thorn, in Prussia, on 28th January, 1755, and died in Frankfort on 2nd March, 1830. He was elected a member of the Munich Academy of Sciences in 1805, made a Knight of the Order of St. Anne of Russia in 1818, and in 1819 was elected an honorary member of the Imperial Academy of Sciences of St. Petersburg. "Pure love of science and the wish to be useful were the motives of his incessant activity." [1]

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[1] Incidentally it may be remarked that the experimenters came to the conclusion that "the velocity is instantaneous".

III

An even more striking illustration of these early strivings for wireless transmission was that made by an anonymous writer in the *Mechanic's Magazine* for 1837. In a letter dated 8th December, "Corpusculum" suggests the use of an earth return precisely as we employ it in wireless to-day. The writer states that five years previously he prepared a specification for a telegraph and that his plan was an improvement upon Alexander's telegraph (in which 31 wires were required) in that it eliminated 15 wires. He proposed to effect this economy by making one wire only serve as the return wire for all the wires. "But even that might be dispensed with," he writes, "where a good discharging train, *as gas or water pipes, at each end of the telegraph could be obtained.*"

In July, 1838, seven months after the publication of "Corpusculum's" letter, Dr. C. A. Steinheil (*b*, Plate VII), Professor of Mathematics and Natural Philosophy at the University of Munich, made an "accidental" discovery of some importance. Steinheil endeavoured to improve upon Sömmering's tub of water experiment by using the earth as a means of conduction, entirely eliminating both wires.

Steinheil was one of the greatest pioneers of the electric telegraph on the Continent, and he endeavoured to use as telegraphic conductors the two lines of a railway track between Nüremberg and Fürth, in accordance with a suggestion previously made by Gauss. As far as the original purpose was concerned, the experiment was a failure owing to the impossibility of obtaining a sufficiently good insulation between the two rails to enable the current to travel from one

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[1] Hamel: *Historical Account of the Telegraph* (1859), p. 34.

S. T. SÖMMERING
(1755-1830)

C. A. STEINHEIL
(1801-1870)

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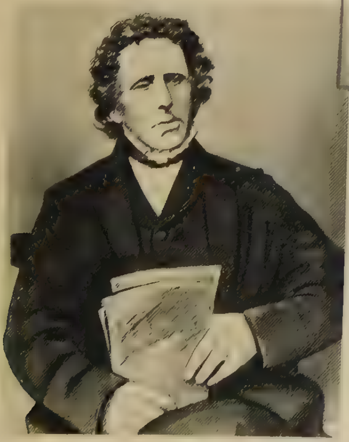

JAMES BOWMAN LINDSAY
(1799-1862)

HENRY HIGHTON
(1816-1874)

station to the other, there to be picked up by suitable apparatus. Having failed in these experiments, however, Steinheil determined to use the earth instead of a second wire, having noticed its great conductibility in his endeavours to obtain perfect insulation of the two rails.

Although "Corpusculum" had publicly suggested a few months earlier that the earth might be used as a return circuit, it would seem that Steinheil's discovery was accidental. Whether this is so or not, however, the fact remains that by using the "earth battery", as it was called, for telegraphic purposes, he introduced a method that, universally adopted, effected a very considerable economy in both wire and labour.

IV

Up to this point Steinheil's experiments do not, perhaps, bear very directly upon wireless, although they must be regarded as pioneer work. However, having succeeded so far in eliminating one of the wires and using the earth battery, he carried out further experiments, as a result of which he is credited with the first intelligent suggestion of a wireless telegraph, the possibility of which was in a manner forced upon him.

> "The inquiry into the laws of dispersion," he wrote, "according to which the ground, whose mass is unlimited, is acted upon by the passage of the galvanic current, appears to be a subject replete with interest. The galvanic excitation cannot be confined to the portions of earth situated between the two ends of the wire. On the contrary, it cannot but extend itself indefinitely, and it therefore only depends on the law that obtains in this excitation of the ground, and the distance of the exciting terminations of the wire, *whether it is necessary or not to have any metallic communication at all for carrying on telegraphic intercourse.*
>
> "An apparatus can, it is true, be constructed in which the inductor, having no other metallic connection with the multiplier than the excitation transmitted through the ground, shall produce galvanic currents in that multiplier sufficient to cause a visible deflection of the bar. This is a hitherto unobserved fact and may be classed amongst the most extraordinary phenomena that science has revealed to us." [1]

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[1] Steinheil: *Telegraphic Communication by Means of Galvanism*, in *Annals of Electricity*, vol. iii, p. 451.

Steinheil pointed out that in practice the suggestion " only holds for small distances, and it must be left to the future to decide whether we shall ever succeed in telegraphing at great distances entirely without metallic connection ".

He proved the possibility of such wireless communication by sending signals up to distances of 50 ft. and suggested that " by augmenting the power of the galvanic induction, or by appropriate multipliers constructed for the purpose, or, in conclusion, by increasing the surface of contact presented by the ends of the multipliers ", it might be possible to send signals over greater distances. " At all events," he concluded, " the phenomenon merits our best attention, and its influence will not perhaps be overlooked in the theoretic views we may form with regard to galvanism itself." [1]

His later and further experiments seem to have been disappointing, however, and he seems to have come to a similar decision as Sömmering in regard to signalling through water. Steinheil wrote that

> " we cannot conjure up gnomes at will to convey our thoughts through the earth. Nature has prevented this. The spreading of the galvanic effect is proportional, not to the distance of the point of excitation, but to the square of this distance. So that, at a distance of 50 ft., only exceeding small effects can be produced by the most powerful electrical effect at the point of excitation. Had we the means which could stand in the same relation to electricity that the eye stands to light, nothing would prevent our telegraphing through the earth without conducting wires, but it is not possible that we shall ever attain this end."[2]

It is interesting to know that Steinheil suggested another means of signalling without wires. His suggestion was to use radiant heat, directed by means of mirrors to a thermo-electric pile. This idea, which is peculiarly similar to that adopted by Graham Bell, will be mentioned again in a later chapter.

V

Morse, the inventor of the code that bears his name, was the next to experiment in telegraphy without wires. Whether or not he had heard of Sömmering's use (in 1811) of the conductibility of water or of Steinheil's work (in 1838) with the "earth battery", we do not definitely know. It seems likely that this knowledge would be in the possession of a man of his attainments, although on his behalf it is claimed that he independently discovered his method of telegraphing without wires. This may be the fact, of course, more especially so because Morse was a born inventor, with a genius for mechanism, who invented machinery and took out patents long before he made his telegraph. Whichever may be correct is not very important, for the fact remains that as a pioneer of wireless he certainly performed some excellent work and we may profitably pause to consider his experiments. Although his ideas for wireless were not sufficiently practical to be commercialized, his work undoubtedly stimulated others and so played an important part in the history of the subject.

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[1] Steinheil : *Telegraphic Communication by Means of Galvanism*, in *Annals of Electricity*, vol. iii, p. 452.

[2] *The Application of Electro-magnetism* (1873), p. 172.

Samuel Finley Breese Morse (*a*, Plate VIII), born at Charlestown, Mass., on 27th April, 1791, was the son of the Rev. Jedediah Morse, D.D., an eminent geographer, author, and inventor, and a descendant of one Anthony Morse, a native of Marlborough, Wilts, who emigrated to America in 1635. At four years of age the boy was sent to an old lady's school and three years later to the preparatory school at Andover. From thence he passed through Phillips's Academy and entered Yale, where he graduated in 1810. Here he began the study of electricity under Jeremiah Day, then Professor of Natural Philosophy at Yale, and Benjamin Silliman, Professor of Chemistry. He soon formed a burning ambition to become an artist, and with this end in view sailed for Europe (in 1811) in the care of Washington Allston, then the greatest artist in America.[1] To him Morse was largely indebted for his subsequent rapid triumph in art. Allston, who was the friend of Wordsworth, Southey, Lamb, and other distinguished men, had studied under Benjamin West, the President of the Royal Academy. He arranged for Morse to study under West, who received him "as a father and a friend", and under his tuition Morse made good progress and was admitted to the Royal Academy in 1811. Two years

[1] The ship was the *Lydia* and the voyage occupied 26 days.

later he was awarded—at the hands of the Duke of Norfolk—the Gold Medal of the Adelphi Society of Arts for a model of the figure of Hercules.[1] This he executed in order to complete with greater effect his picture (which measured 8 ft. by 6 ft. 6 in.) "The Death of Hercules". His painting was exhibited at the Royal Academy Exhibition at Somerset House, and in a letter (24th March, 1813) to his parents, Morse mentioned that he not only had the satisfaction of having the picture accepted, but also of having the praises of the Council who decide on the admission of pictures.

> "Six hundred pictures were refused admission this year," he wrote, "so you may suppose that a picture must possess some merit to be received in preference to six hundred!"

That Morse was undoubtedly an artist of some attainment is shown by the fact that the picture was "placed among the nine best paintings in a gallery of nearly one thousand, and among them the works of Turner, Northcote, Lawrence, and Wilkie".[2]

When Morse came to England it was intended that he should remain there three years, but he stayed over four years. During this time he painted numerous portraits and landscapes and lived in the strictest economy. His letters to his parents during this period are very interesting and give accounts of the life and times in London in the early part of the nineteenth century. In none of them is there any suggestion of the great part he was destined to play in the history of the telegraph, with the exception of his first letter home, written immediately after his arrival in London. In this he expresses a longing that seems prophetic of his great invention when he says:

> "I only wish you had this letter now to relieve your minds from anxiety, for while I am writing I can imagine mother wishing that she could hear of my arrival and thinking of thousands of accidents that may have befallen me. *I wish that in an instant I could communicate the information: but 3,000 miles are not passed over in an instant*, and we must wait four long weeks before we can hear from each other."

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[1] This was during the war between Great Britain and the United States, and Morse often spoke of the award in these circumstances as a pleasing incident that "while a fierce strife was going on between the two nations yet in the fine arts there was a peaceful ground".—Letter from Morse to Rev. E. G. Smith, 1860.

[2] *British Press*, 4th May, 1813.

This letter, yellow with age, is preserved among Morse's papers, and on the outside is pencilled in his own hand (at an unknown date, but probably late in life) the words: " Longing for a Telegraph even in this letter ! "

Morse sailed for America on 21st August, 1815, and after a stormy passage landed at Boston on the 18th October, the passage taking fifty-eight days. He was buoyant with hope and realized that his profession would be his only source of support. He exhibited his great picture " The Judgment of Jupiter ", painted before he left London, " to the admiration of the multitude ", and set up his easel confidently expecting that his fame and work would bring him orders and money. A year passed without an offer being made for his picture nor an order for an historical work. During this time his active mind was at work, however, and with his younger brother he invented and patented an improved pump, one of which (5 in. in diameter and worked only by four men) delivered 360 gallons per minute. This was subsequently developed into a fire-engine and in this form met with some success.

Morse married in 1818 and for some time lived by painting portraits, principally in Charleston, South Carolina, where he made his home. In February, 1820, however, he joined his father in Charlestown, Mass., and here he renewed his studies in electricity and galvanism in the laboratory of Yale College, under Professor Silliman. In 1823 he invented a machine for cutting marble, and in the same year visited Albany, Joseph Henry's town, hoping to obtain orders to paint portraits. In this he was unsuccessful, however, and, reduced almost to his last dollar, he went on to New York and Washington, where in February, 1825, he learned of the sudden death of his wife, who had remained at New Haven.

VI

After a time Morse returned to New York, where (in November, 1825) he established the National Academy of Design. He resided in New York until 1829 industriously following his profession as a painter, and interesting himself in the study of electricity and electro-magnetism under Professor Dana, of Columbia College. Dana, who lectured on electro-magnetism at the Athenæum, was so enthusiastic about the subject that his wife declared she frequently heard him talk of it in his sleep!

It was in 1827 that Morse learned from Dana the elementary facts of Oersted's discovery; the suggestion of Schweigger that magnetism was increased by bending the wire into the form of a ring; and the experiment carried out by Arago, at Ampère's suggestion, to further increase the magnetism by using a series of these rings arranged in the form of a spiral.

In 1829 Morse sailed for Europe and visited London, Paris, and Rome, returning to America in the autumn of 1832. Full of the desire for distinction as a painter and with his mind dwelling on the artistic riches of the galleries he had visited in Italy, he could have had no forethought of the idea that was to come to him during his voyage—an idea that resulted not only in a complete revolution in his life but also in the commerce and intercourse of the whole world.

In October he sailed from Havre on the packet-ship *Sully*, bound for New York, and during the voyage the conversation of his fellow-passengers turned to the recent discoveries in electro-magnetism. Some one asked whether the velocity of an electric current is affected when passing through a length of wire, and on being informed by one of the passengers that electricity travels instantaneously over any length of wire, Morse interposed the remark: "If the presence of electricity can be made visible in any part of the circuit, I see no reason why intelligence may not be transmitted instantaneously by electricity." Although the conversation went on, Morse did not hear it, for the great idea had taken possession of his mind to transmit intelligence and record it at a distance by electricity. He went on deck and commenced to evolve his first telegraph, and in his notebook made also a system of signs to represent letters and figures, composed of a combination of dots and spaces. This was the first idea of the Morse alphabet, universally used in wireless to-day, and it is an extraordinary tribute to the initial efficiency of the Morse code that the basis of the code used in the early days of the needle instrument is the same as that used at the present day in wireless telegraphy. Although when first used the sending speed was, at the most, five words a minute, yet to-day the code is equally efficient when used in the automatic transmitters, capable of sending at speeds of up to 500 words a minute ! [1]

Although the code looks quite simple, yet it was by no means simple to construct. Morse himself appreciated this, for he once stated to a friend that the code was by far the most difficult part of his invention. As originally arranged, the code was not intended to be received audibly, but was to be marked on a moving ribbon of paper.

In formulating his code Morse took as a basis the shortest length of a line—namely, a dot. He then constructed the code of three elements—namely, dot, dash, and space, the latter two being built up in relation to the dot. For instance, the dash was made to equal three dots ; the space separating the letters of a word to equal two dots ; and the space separating words to equal three dots. He paid attention to the important point that letters occurring most frequently in the English language are composed of the shortest elements. The letter " E ", for example, the most used letter in our language, is represented by a single dot.

The first code that Morse evolved is not identical with the code in use to-day, but was what is now called the American Morse code. In this code Morse employed characters that are not in the present code, as for instance " spaced letters ". There were six of these " spaced letters " (namely, C, O, R, Y, Z, and the sign " & "), which were denoted by a space equal to two dots. Morse soon realized the inconvenience of these " spaced letters ", however, finding that in practice there was often a tendency to confound them with the actual space between letters and words, so he eliminated them. He also made other slight modifications, and his improved code is now, with some further minor alterations, the International Morse code used throughout the world. It only remains to remark that the Morse code is by no means perfect. It has, indeed, many drawbacks, the most obvious of which, perhaps, is the fact that the Eastern languages, such as Chinese, cannot be directly transmitted by the Morse alphabet. In such a case it is necessary to translate the message into some European language before sending, and then, of course, retranslate it into its original language at the receiving station.

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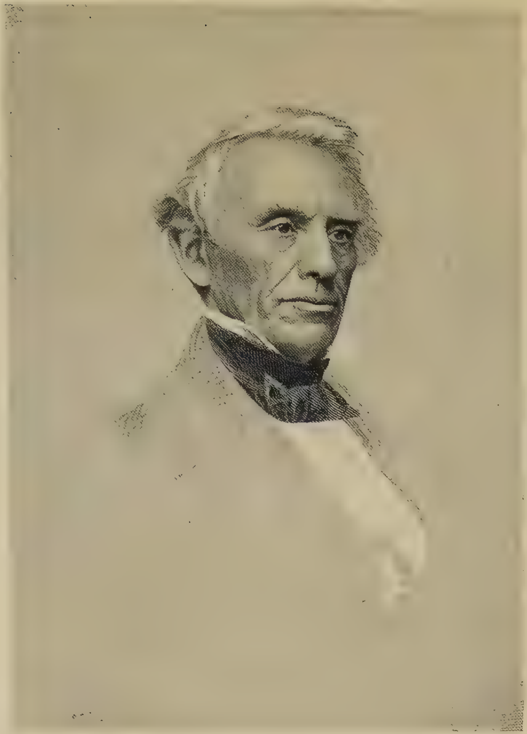
[1] Since this was written a machine has been invented, and satisfactorily tested, to send over 3,000 words per minute.

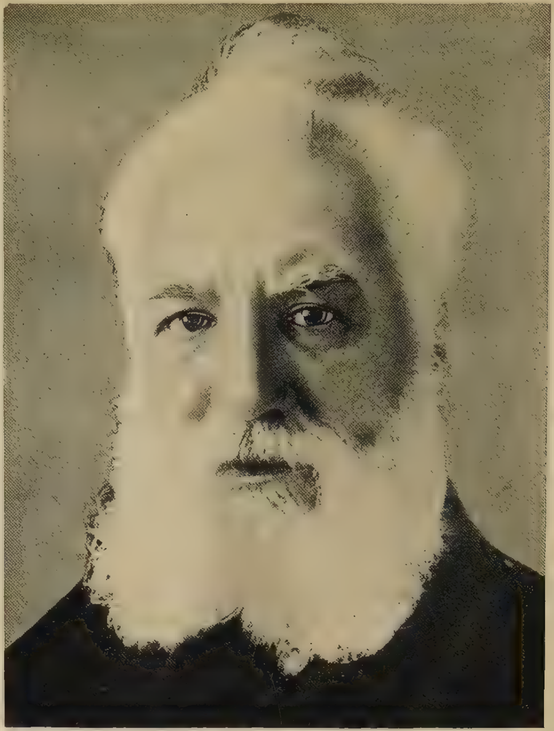
The *Sully* arrived at New York on 15th November, 1832, and Morse was so full of his idea that he commenced to describe it to his brothers almost as soon as he set foot on the wharf. He at once proceeded to construct an instrument with which to test his invention, and so commenced a long and hard struggle that ultimately brought him to abject poverty. He denied himself food and clothing in order to further his experiments, and often was in the depths of despair lest someone should forestall him. For the sake of economy he made everything himself, his models, moulds, and even his castings, and for four years he toiled incessantly. Everything seemed to go wrong. "I am crushed for want of means," he wrote. Success was near at hand, however, and in 1835 he completed his first instrument, which he exhibited to his friends in New York, transmitting signals over a distance of 1,700 ft. In the same year he invented the relay, an instrument of considerable importance to wireless telegraphy.

Morse patented his telegraph on 28th September, 1837, and worked to improve it. He succeeded in transmitting over increasing distances—3½ miles, 5 miles, and 10 miles—and early the following year exhibited an improved instrument to the public. His next step was to bring his telegraph to the notice of the Government, and on 20th February, 1838, he demonstrated his invention before the President and the entire Cabinet. In the following May Morse left for England to patent his idea there.

In the meantime, however, Professor Wheatstone and Mr. Cooke were at work in London on their plan for "improvements in giving signals and sounding alarums in distant places by means of electric currents transmitted through metallic circuits". Morse did not succeed in patenting his device in England owing to the unjust attitude of the Attorney-General, Sir John (afterwards Lord) Campbell, who seems to have gone out of his way to deprive the inventor of his rights. Morse then left England for France, where he had no difficulty in securing a patent. In all these travels Morse took with him his bulky apparatus, including the all-important electro-magnet, the arms of which were 18 in. in diameter, the whole



SAMUEL FINLEY BREESE MORSE
(1791-1872)



ALEXANDER GRAHAM BELL
(1847-1923)

weighing no less than 185 lb. It was during this visit that he met Daguerre in Paris and learned how the daguerrotype process had been perfected. With Draper he shares the honour of being the first in America to take photographs of living persons.

In April the following year Morse returned to America by the *Great Western* and was disappointed to find that nothing had been done in regard either to making him a grant towards the cost of his experiments or authorizing the installation of an experimental telegraph. In fact, with the exception of his friends and some of the leading scientists, his countrymen seemed to be quite indifferent to his invention. In 1843, however, a few moments before midnight in the last day of the session, a grant of £6,000 was made, by a narrow majority of eight votes, for an experimental telegraph between Washington and Baltimore.

VII

A few months before the grant was made Morse endeavoured to arouse interest in his invention by giving a public demonstration of the fact that an electric current will travel as well along a cable laid through water as along an air line. On the night of 18th October, 1842, he laid insulated wires between Governor's Island and Castle Garden, New York, a distance of about a mile. At daybreak on the following morning he prepared to give his demonstration, and had transmitted three or four characters when communication was suddenly interrupted, owing to one of several vessels lying along the line of the submerged cable raising the cable on her anchor. Not understanding what they had hauled on board and finding no end to the cable, the sailors hauled about 200 ft. on deck, cut it off, and took it away with them!

With the jeers of the disappointed spectators ringing in his ears, Morse " immediately devised a plan for avoiding such an accident in the future, by so arranging my wires along the banks of the river as to cause the water itself to conduct the electricity across ". He laid a wire along each bank, connecting one wire with the transmitting key and with a battery and the other wire on the opposite bank with a receiver, the ends of both wires being fastened to copper plates (P P, Fig. 11) sunk in the river.

> " On 16th December, 1842, I tested my arrangement across the canal (at Washington) and with success," wrote Morse, " and the simple fact was then ascertained that *electricity could be made to cross a river without other conductors than the water itself*." [1]

It was not until the autumn of 1844 that Morse " had the leisure to make a series of experiments to ascertain the law " regarding the passage of an electric current through water. He then carried out similar experiments but on a larger scale. He found that " electricity crosses the river in quantity in proportion to the size of the plates in the water ". He also found that " the distance of the plates on the same side of the river from each other also affects the result ". Having ascertained the general law governing wireless communication through water, and wishing now to discover the best practical distance at which the plates should be placed, he requested his friend, Professor L. D. Gale, to carry out a series of further experiments. From these it was determined that the best results were obtained when the distance between the plates on the same bank was three times greater than the width of the river. Gale found that no increase of power was obtained if the distance of the plates from each other was increased by four times.

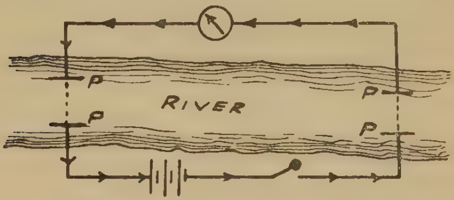


FIG. 11—MORSE'S EXPERIMENT FOR WIRELESS COMMUNICATION BY CONDUCTION

Commenting on the results of these experiments Morse wrote :

> " It would seem that there may be situations in which the arrangements I have made for passing electricity across rivers may be useful. . . . The experiments made were but for a short distance, in which, however, the principle was fully proved to be correct. It has been applied under the direction of my able assistants, Messrs. Vail and

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[1] From Morse's letter (23rd December, 1844) to the Secretary of the Treasury.

Rogers, across the Susquehanna River, at Havre-de-Grace, with complete success, a distance of nearly a mile." [1]

Little did Morse think that he was actually on the threshold of an even greater revolution than that brought about by the introduction of his telegraph. But it is perhaps fortunate that he missed the great issue, for undoubtedly the time was not ripe for wireless telegraphy—indeed, as every student of his life will find, it was only his indomitable will and dogged perseverance that enabled him to succeed with his line electric telegraph. Had wireless been discovered in those days, it would undoubtedly have suffered disastrously from being before its time, as have many other inventions that have come before the world was able to appreciate them.

The years of Morse's early work on his invention were full of bitterness and disappointments, but it is pleasing to know that he reaped the joy of his labours in his later life. He lived to see his system of telegraphy adopted by the United States, France, Germany, Denmark, Sweden, Russia, and Australia. Napoleon III was instrumental in his being presented with an international gift of £80,000, and he died, loaded with honours, on 2nd April, 1872, in New York.

VIII

About the same time that Morse was at work in America, Lindsay was experimenting at Dundee, and his extensive labours in this field—and also in connection with electric lighting—never had the appreciation they certainly merited. As was the case with Morse, Lindsay also used the conductive properties of water in the attempt to evolve a practical means of communication without wires, and as he commenced his experiments with this particular object in view, and as Morse was accidentally led to investigate the subject, it is perhaps not unjust to say that a greater share of credit is due to Lindsay. More especially is this the case, perhaps, as he actually perfected a practical system of wireless communication by conduction, whereas with Morse the subject may be said to have never passed beyond the experimental stage.

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[1] Vail: *American Electro-Magnetic Telegraph* (1845).

From transmission through water to transmission through ether is a far cry, and although these pioneer methods of Morse and Lindsay may not appear to have a close bearing upon wireless of to-day, we must remember that they were actual links in the chain by which our present wireless systems have been built up. Even if no other good could be said to have resulted from Lindsay's work, it at least served to attract the attention of Sir W. H. Preece and to interest him in the subject, with results that we shall shortly describe.

James Bowman Lindsay (*c*, Plate VII) was born on the 8th September, 1799, at Carmyllie, a little village in Forfarshire, not far from J. M. Barrie's "Thrums". Lindsay would certainly have followed his father's occupation of farming had not his delicate constitution made this impossible. Instead, he was placed as a "bot", or learner, under the care of a local hand-loom weaver, the intention being that he should follow that occupation.

In his early days Lindsay showed a decided inclination for study, which his work at the loom did not interrupt. It is related that often the lad would be seen on his way to Arbroath with a web of cloth firmly strapped on his back and an open book in his hand. After delivering his cloth and obtaining fresh material, he returned to Carmyllie in the same fashion and still reading his book. The development of his studious nature persuaded his parents that he might become something better than a weaver, and with true Scottish self-denial they decided to limit their expenses so that their boy might have the privilege of a college education. They were able to send him to St. Andrews University, and here, notwithstanding the disadvantages of having been self-educated, Lindsay won for himself a distinguished place, especially in mathematics and physical science. He matriculated in 1821, when 22 years of age.

Following the ancient custom of poor Scottish students, Lindsay worked at a trade during his holidays, at first as a hand-loom weaver, but later he took private pupils, and was thus able to continue his own studies at the same time. It would seem that his first intention was to devote himself to the ministry, for, having completed his Arts course, he entered Divinity Hall to complete his studies in theology. Before becoming a licentiate of the Church of Scotland, however, a new avenue was opened to him and (in 1829) he was appointed Lecturer in Science and Mathematics at the Watt Institution in Dundee, then under the charge of a Mr. Macintosh.

Lindsay is described as having been

> "a man of profound learning and untiring scientific research, who, had he been more practical, less diffident, and possessed of greater worldly wisdom, would have gained for himself a good place amongst distinguished men. As it was, he remained little more than a mere abstraction, a cyclopedia out of order, and went through life as a poor and modest schoolmaster. At the time I knew him he was devoting much of his attention to a study of electricity, particularly to the celerity with which it is transmitted to any distance and the readiness by which the alternating effects may be translated into speech. I have no doubt he held in his hand the modern system of telegraphy, but it needed a wiser man than he to turn it to practical use. He also produced from galvanic cells a light that burned steadily for a lengthened period." [1]

In 1833 Lindsay formed classes in Dundee for instruction in science, and the direction of his scientific investigations and the scope of his teaching is well shown by the following advertisement:

> "J. B. Lindsay resumes classes for cultivating the intellectual and historical portions of knowledge and instruction on 14th April, 1834, in South Tay Street, Dundee. In a few weeks hence a course of lectures will be formed on frictional, galvanic, and voltaic electricity, magnetism, and electro-magnetism. The battery, already powerful, is undergoing daily augmentation. The light obtained from it is intensely bright, and the number of lights may be increased without limit. A great number of wheels may be turned [by electricity] and small weights raised over pulleys. Houses and towns will in a short time be lighted by electricity instead of gas, and heated by it instead of coal; and machinery will be worked by it instead of steam—all at a trifling expense. A miniature view of all these effects will be exhibited, besides a number of subordinate experiments, including the discoveries of Sir Humphry Davy." [2]

In March, 1841, Lindsay was appointed teacher in the Dundee Prison (at a salary of £50 per annum), a post he held for seventeen years, resigning in October, 1858. His skill as a teacher among the prisoners was considerable, and one of his pupils, with whom he took special pains, subsequently became an astronomer of note. Soon after he had entered on his duties at the prison he was offered a position on the scientific staff of the British Museum, but as the appointment would have necessitated leaving his aged mother, he decided not to accept the offer.

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[1] Alexander Maxwell, F.S.A. Scot. (historian of old Dundee), in his unpublished *Reminiscences*.

[2] *Dundee Advertiser*, 11th April, 1834.

At St. Andrews Lindsay had not shown any special proficiency in the study of languages, but his interest being aroused, he pursued the subject with characteristic energy. In 1828 he began to compile the *Pentecontaglossal Paternoster, or the Lord's Prayer in Fifty Languages*, which he thought would bring him fame. For more than a quarter of a century he spent all his spare time upon this remarkable compilation, which was published in 1846 in a limited edition and is now rare. In 1858 he published his *Chrono-Astrolabe: a Full Set of Astronomical Tables*, intended to assist in the calculation of chronological periods, and this attracted some notice at the time of publication.

IX

When Lindsay first demonstrated a continuous light produced by electricity, the position was that intermittent electric light was known only as an advanced laboratory experiment. In September, 1800, Sir Humphry Davy had produced a spark from wood-charcoal by passing a voltaic current through the material, which experiment Moyes of Edinburgh had repeated in 1801. In March, 1802, Robertson, the aeronaut, exhibited in Paris an electric light from charcoal, but only as an intermittent spark. Davy in 1809 first showed a continuous arc light from charcoal points with a battery of 200 pairs of zinc and copper plates. In 1809 and 1811 passing references were made to the possibility of electric light; and in 1834 it was stated in the *Mechanic's Magazine* that a carbon point in an electrical circuit could be made to produce a brilliant but intermittent light.

Included in Lindsay's papers, which were collected and handed over to the Trustees of the Dundee Public Library in 1893, was the following interesting fragment of autobiography, which fixes the time when Lindsay began his experiments in electricity.

" Previous to the discovery of Oersted I had made many experiments on magnetism, with the view of obtaining from it a motive power.[1] No sooner was I aware of the deflection of the needle and the multiplication of the power coils of wire, than the possibility of power appeared certain, and I commenced a series of experiments in 1832. The power on a small scale was easily obtained, and during these experiments I had a clear view of the application of electricity to telegraphic communication.

" The light also drew my attention and I was in a trilemma whether to fix upon the power, the light, or the telegraph. After reflection I fixed upon the light as the first investigation, and I made many contrivances for augmenting it and rendering it constant. Several years were spent in experiment, and I obtained a constant stream of light on 25th July, 1835. Having satisfied myself on this subject, I returned to some glossological investigations that had been left unfinished, and was engaged with these until 1843. In that year I proposed a submarine telegraph across the Atlantic, after having proved the possibility by a series of experiments. Enquiries on other subjects have since that time engaged my attention, but I eagerly desired to return to electricity."

Lindsay's discovery of electric lighting was thus announced:

" Mr. Lindsay, a teacher in this town, formerly lecturer to Watt Institution, succeeded on the evening of the 25th July in obtaining a constant electric light. It is upwards of two years since he turned his attention to this subject, but much of that time has been devoted to other avocations. In beauty the light surpasses all others, has no smell, emits no smoke, is incapable of explosion, and not requiring air for combustion can be kept in sealed glass jars. It ignites without the aid of a taper, and seems peculiarly calculated for flax houses, spinning mills, and other places containing combustible materials. It may be sent to any convenient distance, and the apparatus for producing it is contained in a common chest." [2]

In a letter that Lindsay wrote about this time he made the following remarkable prophecy, which, however, he did not live to see fulfilled:

" As a notice of my electric light has been extensively circulated," he wrote, " some persons may be anxious to know its present state and my views respecting it. The apparatus that I have at present is merely a small model. It has already cost me a great deal of labour and will cost a good deal more before my room is sufficiently lighted. Had circumstances permitted, it would have been perfected two years ago, as my plans were formed then. I am writing this letter by means of it at 6 in. or 8 in. distant, and I can read a book at a distance of 1½ ft. From the same apparatus I can get two or three lights, each of which is fit for reading with. I can make it burn in the open air, or in a glass tube without air, and neither wind nor water is capable of extinguishing it. It does not inflame paper nor any other combustible. These are facts.

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[1] The announcement of Oersted's discovery of the deflection of the magnetic needle under the influence of an electric current was made in 1820, and apparently Lindsay was then making researches in the same direction

[2] *Dundee Advertiser*, 31st July, 1835.

"As I intend in a short time to give a lecture on the subject, my views on the further progress will be unfolded then. A few of these, however, may be mentioned just now. Brilliant illuminations will be obtained by a light incapable of combustion; and on its introduction to spinning mills, conflagrations will be unheard of. Its beauty will recommend it to the fashionable, and the producing apparatus may be framed and stand side by side with the piano in the drawing-room.

"Requiring no air for combustion, and emitting no offensive smell, it will not deteriorate the atmosphere in a thronged hall. Exposed to the open air, it will blaze with undiminished lustre amidst tempests of wind and rain; and, being capable of surpassing all lights in splendour, it will be used in lighthouses and for telegraphs. The present generation may yet have it burning in their houses and enlightening their streets.

"Nor are these predictions the off-shoots of an exuberant fancy or disordered imagination. They are the anticipated results of laborious research and of countless experiments. Electricity, moreover, is destined for mightier feats than even universal illumination." [1]

Lindsay's lecture was delivered in the Thistle Hall on 15th January, 1836, and was repeated in the same place on 21st April, 1837. Unfortunately there are no records of the apparatus used, though it is probable that a voltaic battery of some kind supplied the current for the experiments.

Lindsay's scientific discoveries attracted the notice of several eminent men of science, and his name was mentioned to the Prime Minister, the Earl of Derby. In July, 1858, he granted Lindsay an annual pension of £100, "in recognition of his great learning and extraordinary attainments". Lindsay was thus enabled to devote himself entirely to his literary and scientific pursuits.

X

Although Lindsay studied the working of the electric telegraph as early as 1830, some five years before the idea had advanced beyond a laboratory state, he does not appear to have gone very deeply into the subject until about 1843. In that year he proposed to connect Britain and America by a single wire, using Steinheil's "earth battery" to complete the circuit.

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[1] *Dundee Advertiser*, 30th October, 1835.

Nothing was heard of Lindsay or his scheme until 1853, when he gave a lecture in Dundee on *Telegraphic Communication.* In the course of his remarks he said: "The principle of submerged wires, such as those now used for telegraphic intelligence between this country and Ireland and France, is no longer necessary. By a peculiar arrangement of wires at the sides of rivers or seas, the electrical influence can be made to pass on through the water itself."

Lindsay successfully demonstrated the possibility of his suggestion on a small scale by means of a water trough.[1] The lecture was repeated at Glasgow in the following August, and Lindsay became so convinced of the practicability of his plan that (on 5th June, 1854) he patented it. His specification explains that the "invention consists of a mode of transmitting telegraphic messages by means of electricity or magnetism through and across water without submerged wires, the water being made available as the connecting and conducting medium, by the following means:

> "On the land, on the side from which the message is to be sent, I place a battery and telegraph instrument, to which are attached two wires terminating in metal balls, tubes, or plates placed in the water or in moist ground adjacent to the water, at a certain distance apart, according to the width of the water to be crossed (the distance between the two balls, plates, or tubes to be greater than across the water when practicable).
>
> "On the land which is situated on the opposite side of the water, and to which the message is to be conveyed, I place two similar metal balls, plates, or tubes, immersed as above stated, and having wires attached to them which lead to, and are in connection with, another battery and needle indicator, or other suitable telegraphic instrument. A, A in the diagram [see Fig. 12] show the position of the battery and instrument on one side of the water, Z; B, B, the battery and instrument on the opposite side; C, D, E, F, metallic or charcoal terminators; G, H, I, K, wires insulated in the usual way, and connecting the terminators, batteries, and instruments, as shown.
>
> "As regards the power or primary agent, it may be either voltait,

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[1] *Dundee Advertiser*, 18th March, 1853.

galvanic, or magnetic electricity, and the apparatus for evolving the same such as is used for ordinary telegraphic purposes.

" As regards the indicating apparatus, I propose to employ any of the instruments in known use which are most efficient for my purpose, observing that the needle indicator may be arranged either in a vertical or in a horizontal position, and that the coil of wire which actuates the needle may be increased or diminished according to circumstances.

" Suppose it is required to transmit a message from A, the operator completes the circuit of the electric current as ordinarily practised. It will be evident that the current will have two courses open to it, the one being directly back through the water from C to D, and the other across the water from C to E, along the wires I K, through the instrument B, and back from F to D. Now, I have found that if each of the two distances C D and E F be greater than C E and D F, the resistances through C E and D F will be so much less than that through the water between C and D, that more of the current will pass across the water, through the opposite wires, and recross at F, than take the direct course C D; or, more correctly speaking, the current will divide itself between the two courses in inverse ratio to their resistances. As cases may arise, from local or other causes, such as not to admit of the distance between the immersed plates being greater than the distance across the water, I propose, then, to augment the force of the batteries, and to increase the size of the plates, so as to compel a sufficient portion of the current to cross. I prefer, however, when circumstances admit of it, employing the first method."

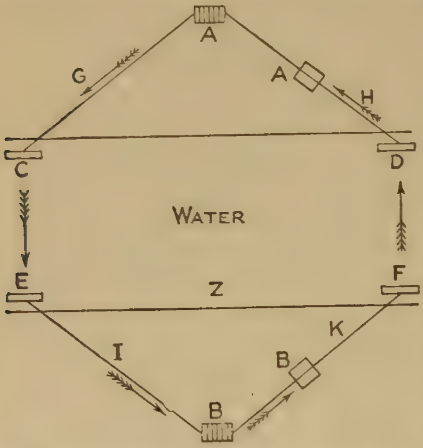

FIG. 12—LINDSAY'S METHOD OF SIGNALLING BY CONDUCTION

The first public trials of Lindsay's wireless telegraphic system were held in 1854 across the Earl Grey Dock, Dundee, and later across the Tay at Glencarse, where the river is about three-quarters of a mile in width. We are told that Lindsay stationed his friends on one side of the Tay, enjoining them to watch the galvanometer and note how the needle moved. He then inserted his plates in the water on their side of the river, and crossed over to the opposite side to complete his arrangements. With a battery of twenty-four Bunsen cells he made some momentary contacts, reversing the connections a few times so as to produce right and left deflections of the galvanometer needle. Then he returned and compared the deflections of the needle that his friends had noted with the order in which he had himself made the battery contacts, and on finding them to correspond was supremely happy.[1]

XI

After these tests Lindsay journeyed to London and brought his system to the notice of the Electric Telegraph Company, and Sir (then Mr.) W. H. Preece was commissioned to investigate the inventor's claims. Experiments were made in a special testing tank at Percy Wharf on the Thames, and the feasibility of the plan was proved. It was here that Lindsay heard from Mr. Preece that his " great invention " was not new—that twelve years earlier Morse had obtained similar results in America, and that Alexander Bain had also tried (about the same time) the experiment on the Serpentine.[2]

Lindsay does not seem to have been dismayed by this news, however, for he went on to Portsmouth, where (in August, 1854) he conducted a further series of experiments, transmitting signals across the mill dam over a distance of about 500 yards.[3] He seems to have repeated these experiments whenever and wherever he had the opportunity, his most elaborate test being across the Tay, when he succeeded in signalling from Dundee to Woodhaven, where the river is nearly two miles in width.

In September, 1859, he again carried out experiments across the River Dee, and read a paper before the British Association at Aberdeen *On Telegraphing Without Wires.* In his paper he mentioned that he had been engaged on the subject since 1831, and that his experiments had shown that only a fractional part of the current crosses through the water from one side of the river to the other. The quantity that does cross, he said, may be increased in four ways: (1) by an increased battery power, (2) by increasing the surface of the immersed sheets, (3) by increasing the coil that moves the receiving needle, and (4) by increasing the lateral distance of the sheets. He pointed out that in telegraphing to Ireland or France by this method the necessary lateral distance between the plates could be easily obtained, but for communicating with America the lateral distance in Britain was much less than the distance across. According to his calculations, a battery of 130 sq. ft. of zinc, immersed plates of 3,000 sq. ft., and a coil of 200 lb. would be sufficient to establish wireless communication with America, with the lateral distance that could be obtained in Great Britain. The paper was commended by Lord Rosse, Michael Faraday, and the Astronomer Royal, Sir G. B. Airy. Lord Kelvin was also present, and with his 40 years' experience of electricity one wonders what he thought of the Dundee weaver's plan—more especially as he was at that time deeply concerned in the laying of the Atlantic cable.

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[1] Kerr: *Wireless Telegraphy* (1898), p. 40.

[2] For further details see *The Artisan*, 30th June, 1843, p. 147.

[3] *Morning Post*, 28th August, 1854, and *Chambers's Journal*, September, 1854.

In February, 1860, Lindsay repeated his experiments at Liverpool, but there, for some reason, he was unsuccessful. The experiments failed, being "counteracted by some unaccountable influences that he had not before met with". In July of the same year he transmitted a current across the Tay, below the Earn, where the river is over a mile in width. Although he did not subsequently conduct any further public experiments in telegraphing without wires, Lindsay was fully convinced of the soundness of his views, and until his death remained confident of their ultimate adoption.

Lindsay was never married, and after the death of his mother he lived alone in Union Street, Dundee, surrounded by his books and apparatus. When his health began to fail (in 1860) a niece from Carmyllie kept house for him. A family dispute led to her return to her parents, however, and from that time until his death he lived by himself, wholly absorbed in his scientific studies. His kitchen was filled with galvanic apparatus that he had made himself, and from which he obtained his electric light—at a cost of "about half a farthing per week", as he once told some one. His living-room was so crowded with books and instruments that it was difficult to move about in it.

One of his friends, who was much in his company during his later years, thus described his usual day's work: "He rose every morning at four o'clock, and after a frugal breakfast worked until noon, when he would go out to a restaurant for dinner. After dinner a short walk round the docks was his rule, then back to his studies, refreshing himself with a cup of tea, and retiring about eleven o'clock."

Lindsay spared no expense in securing the rarest books of antiquity, and often commissioned large purchases from booksellers in London and Paris. As an example of the extent to which he went may be mentioned the occasion when he was studying eclipses in order to correct dates in history. It took him three years to construct his *Chrono-Astrolabe*, and during this time he purchased all available records of authentic accounts of eclipses, expending about £200 in this connection. His purchases included the works of Ptolemy and the Byzantine historians, the Asiatic researches, and a series of forty-two volumes of the *Nautical Almanac*. He learned to his dismay that the works of Confucius were not to be found anywhere in Europe, and it was only when Lord Lindsay came to his aid that he was successful in securing a copy. His passion for purchasing books and for acquiring the instruments necessary for his researches led him to starve himself to such an extent that he stinted his body in order to satisfy his mind. When at length disease came upon him, he was not able to throw it off and died (on 19th June, 1862) after five days' illness.

CHAPTER VI

FURTHER EXPERIMENTS WITH CONDUCTION: THE HIGHTONS, DR. O'SHAUGHNESSY, BOURBOUZE, AND OTHERS

THE REV. HENRY HIGHTON (1816–74), who with his brother Edward carried out many experiments in wireless telegraphy, was educated under the famous Dr. Arnold of Rugby, and was principal of Cheltenham College 1859–62. In 1844 he took out a patent (No. 10257, 10th July) for a system of telegraphy based on static electricity. He was awarded a Gold Medal in 1849 and the Prince of Wales's Medal in 1863 for his discoveries in this field.

Sometime previous to 1852 he and his brother succeeded in communicating over a distance of about a quarter of a mile with bare wires sunk in canals, but, according to Edward, the experiments—made "for the purpose of ascertaining the mathematical law that governs the loss of power when no insulation is used"—proved "that telegraphic communications could not be sent to any considerable distance without the employment of an insulated medium".[1]

Henry Highton (*d*, Plate VII) was more optimistic, however, and believing in the practicability of the system, continued his experiments on the banks of the Thames. In a paper, entitled *Telegraphy Without Insulation*, read before the Society of Arts (on 1st May, 1872) he gave three methods for the successful working of his scheme. He stated that he had for many years

> "been convinced of the possibility of telegraphing for long distances without insulation, or with wires very imperfectly insulated; but till lately I had not the leisure or opportunity of trying sufficient experiments bearing on the subject. I need scarcely say that the idea has been pronounced on all hands to be entirely visionary and impossible,

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[1] E. Highton: *The Electric Telegraph, its History and Progress* (1852).

and I have been warned of the folly of incurring any outlay in a matter where every attempt had hitherto failed. But I was so thoroughly convinced of the soundness of my views, and of the certainty of being able to go a considerable distance without any insulation, and any distance with very imperfect insulation, that I commenced, some three or four months since, a systematic series of experiments with a view to testing my ideas practically.

"I began by trying various lengths of wire, dropped in the Thames from boats, and found that I could, without the slightest difficulty, exceed the limits allowed hitherto as practicable. This method, however, was attended with much difficulty and inconvenience, owing to the rapidity of the tides and the motion of the boats. I next tried wires across the Thames, but had them broken five or six times by the strength of the current and by barges dragging their anchors across them. I then put the instrument in my own room, on the banks of the river, and sent a boat down stream with a reel of wire and a battery to signal to me at different distances. The success was so much beyond my expectations, that I next obtained leave to lay down wires in Wimbledon lake.

"As the result of all these experiments I found that water is so perfect an insulator for electricity of low tension that wires charged with it retained the charge with the utmost obstinacy; and, whether from the effect of polarization (so called), or, as I am inclined to suppose, from electrization of the successive strata of water surrounding the wire, a long wire, brought to a state of low electrical tension, will retain that tension for minutes, or even hours. Notwithstanding attempts to discharge the wire every five seconds, I have found that a copper surface of 10 or 12 sq. ft. in fresh water will retain a very appreciable charge for a quarter of an hour; and even when we attempt to discharge it continuously through a resistance of about thirty units [ohms], it will retain an appreciable, though gradually decreasing, charge for five or six minutes.[1]

"Since that time I have constructed an artificial line, consisting of resistance coils, condensers, and plates of copper in liquids, acting at once as faults and condensers, so that I might learn as far as possible to what extent the principle of non-insulation can be carried. I have satisfied myself that, though there are difficulties in very long depths absolutely uninsulated, yet it is quite feasible to telegraph, even across the Atlantic. . . .

"The instrument with which I propose to work is the gold-leaf instrument, constructed by me for telegraphic purposes twenty-six years ago, acted upon by a powerful electro-magnet and with its motions optically enlarged. The exclusive use of this instrument in England was purchased by the Electric and International Telegraph Company, but it was never practically used, except in Baden, where a Government commission recommended it as the best. One of its chief merits is its extreme lightness and delicacy Judging by the resistance it presents to the electric current, it would appear that the piece of gold-leaf in the instrument now before us does not weigh more than $\frac{1}{2000}$ part of a grain; let us even say that it weighs four times more, or $\frac{1}{500}$ part of a grain. In order, then, to make a visible signal we only have to move a very, very small fraction of a grain through a very, very small fraction of an inch. You may judge of its delicacy when I show you that the warmth of the hand, or even a look, by means of the warmth of the face turned towards a thermopile, can transmit an appreciable signal through a resistance equal to that of the Atlantic cable.

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[1] There is evidently some error here, for an effect such as Highton describes would obviously cause his method to be impracticable.

"Another great merit of this instrument is its ready adaptability to the circumstances in which it may be placed, as it is easy to increase or diminish the length, or breadth, or tension of the gold-leaf. Thus, increase of length or diminution of breadth increases the resistance, but also increases the sensitiveness; and again, partaking as it does partly of the character of a pendulum and partly of a musical string, the rapidity of vibration is increased by giving it greater tension and greater shortness, though by doing so the sensitiveness is diminished; so that you can adjust it to the peculiar circumstances of any circuit. Again, you notice the deadness of the movements and the total absence of swing, which, whenever a needle is used, always more or less tends to confuse the signals. The greatest advantage of all is that we can increase the sensitiveness without increasing the resistance, simply by increasing the power of the electro-magnet.

"Having now explained the construction of the instrument and pointed out its merits, I proceed to show by experiment how tenaciously a piece of copper in water will retain a state of electrical tension. Here is a tub of fresh water, with copper plates presenting to each other about 14 sq. ft. of surface. I charge these plates with a Daniell cell, and you see how they retain the charge—in fact, they will go on gradually discharging for several minutes through the small resistance of the gold-leaf instrument. I now do the same with a tub of salt water, and the result is still the same, though less marked. In fact, these plates, with the water between, represent the two metallic surfaces of a Leyden jar, and the water retains the electricity of this small tension with much more obstinacy than the glass of a Leyden jar does the electricity of a higher tension.

"Indeed, it is a fact of the highest importance in telegraphy that when there is a fault, electricity of a high tension, say of twenty or thirty Daniell cells, will almost wholly escape by it, and leave nothing for the instrument; whereas electricity of a small tension, as from a single cell of large surface, will pass through the instrument with very little loss of power. This is strikingly shown by the use of an ordinary tangent galvanometer. I cannot well show it to a large audience like the present, therefore I will only inform you that when I have taken two currents, each marking 30° on the galvanometer, the one of high tension from thirty Daniell cells and the other of low tension from a single cell of small internal resistance, a fault equivalent to the exposure of a mile of No. 16 wire in sea-water will annihilate all appreciable effects on the galvanometer when using the current of high tension, whereas the current of low tension will still show as much as 20°. You see, then, the importance of using currents of low tension from a battery of large surface, and how a faulty cable can be worked with such currents when it is absolutely useless with currents of high tension.

"There are three ways of signalling without insulation; one, only feasible for short distances; a second, which I think will be found the most practicable; and a third, in the practical working of which for very long distances several difficulties (though by no means insuperable) present themselves.

"To explain the first plan, we will take the case of a river, and in the water near one bank place the copper plates A B [Fig. 13], and connect them with a wire, including the battery P. Near the opposite bank submerge similar plates, C D, connected by a wire, in the circuit of which is placed the galvanometer G. Between A and B the current will pass by every possible route, in quantities inversely proportional to their resistances; parts will pass direct by A B; and other portions by A, C, D, B, and by A, C, G, D, B. Now, if the plates be large, and A C and B D respectively comparatively near to each other, an appreciable current will pass from A to C, through G, and back from D to B; but if the plates be small, the battery power small, and the distance from A to B and from C to D comparatively short, no appreciable amount will pass through the galvanometer circuit."

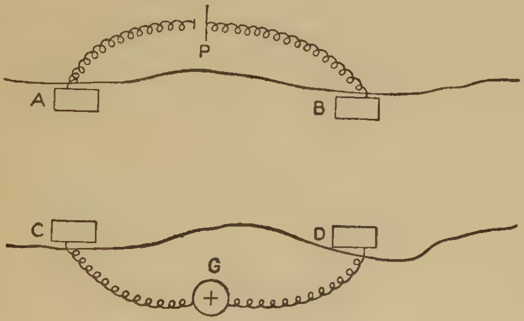

FIG. 13—HIGHTON'S SYSTEM

II

Highton's plan was, of course, similar in detail to the method used by Morse, but he intended to work on a considerably larger scale. His great optimism may be gathered from the fact that he did "not hesitate to say that it is possible, by erecting a very thick line wire from the Hebrides to Cornwall, by the use of enormous plates at each extremity, and by an enormous amount of battery power—i.e. as regards *quantity*—to transmit a current that would be sensibly perceived in a similar line of very thick wire, with very large plates, on the other side of the Atlantic". He pointed out, however, that "the trouble and expense would probably be much greater than that of laying a wire across the ocean". His second, "the simplest and most feasible plan", was to lay two wires across the water, separated from each other. Currents of low tension, obtained from batteries of large surface, were to be employed, it being intended to work with that portion of the current that preferred to pass through this metallic circuit instead of passing through the liquid conductor.

In his third method he proposed to lay a single wire imperfectly insulated, and to place at the opposite end beyond the instrument a very large earth-plate. Any electrical tension thrown on this wire would transmit itself more or less to the opposite end, and would be shown on any instrument of small resistance and sufficient delicacy.

> "There are certain difficulties in this way of working," he said, "such as the effects of earth-currents and currents of polarization which keep the needle or gold-leaf permanently deflected from zero, necessitating special means of counteraction. I have no doubt, from my experiments, that these difficulties may be overcome, but still I think the simplest and most feasible, and not more expensive, plan will be to work with two naked wires kept apart from metallic contact, using electricity of a very low tension."

III

Of these three plans Highton believed the second to be the most workable, and the method was, in fact, identical with that largely used in India in the early days of the telegraph to overcome the great difficulty in crossing the great rivers and waterways. So far as one is able to trace, the scheme was first used in 1849 by Dr. O'Shaughnessy, who afterwards became Sir William O'Shaughnessy Brooke. In that year he laid a bare iron rod across the bed of the River Haldee, at a point where it is 4,200 ft. in width. Signals were passed, but "it was found that the instruments required the attention of skilful operators, and that in practice such derangements occurred as caused very frequent interruptions". A further test was then made, using the water alone to carry the current. Signals were again passed, but, although 250 cells were being used, they were very faint, and to make the scheme practicable would have necessitated enormous battery power. In 1858 O'Shaughnessy wrote: "I have long since ascertained that two naked uncoated wires, kept at a moderate distance—say 50 or 100 yards—apart will transmit electric currents to considerable distances (two or three miles) sufficiently powerful for signalling with needle instruments."

The experiments of Morse, Lindsay, and the Hightons soon became common knowledge, with the result that many additional workers were attracted to the subject, both in this country and abroad. In this country there were several, including G. E. Dering (1853), who advocated the bare wire system; and J. Haworth (1862), who patented "an improved method of conveying electric signals without the intervention of any continuous artificial conductor", which method is at least distinguished by the fact that no one has ever been able to understand it! Abroad, Bonelli in Italy; Gintl, the inventor of a duplex telegraph, in Austria; and Bouchotte and Douat in France, all engaged themselves in experiments, but as the results they achieved do not show any striking advances on the methods of which Morse may be regarded as the pioneer, we shall pass them by.

It is perhaps of interest to mention that between 1858 and 1874 a large number of patents was taken out (and the specifications are to be seen to-day at the Patent Office in London) dealing with the subject, chiefly on the lines of one or other of the methods already described, with or without the earth battery. These generally use the bare wire system of Highton and Dering, and are unsupported by either experimental proofs or any claims to originality. A list of some of these is given on the following page.

Name of Patentee.	No.	Date of Patent.
B. Nickels	2317	16th October, 1858
A. V. Newton	2514	9th November, 1858
A. Barclay..	56	7th January, 1859
A. Barclay..	263	28th January, 1859
J. Molesworth	687	18th March, 1859
H. S. Rosser	2433	25th October, 1859
W. E. Newton	1169	11th May, 1860
H. Wilde	2997	28th November, 1861
Lord A. S. Churchill ..	458	20th February, 1862
H. Wilde	3006	1st December, 1863
H. Wilde	2762	26th October, 1865
T. Walker	2870	6th November, 1866
T. Walker	293	23rd January, 1874

IV

It may be interesting to mention here that during the winter of 1870–1, when Paris was besieged by the Germans, M. Bourbouze, a well-known French electrician, proposed to re-establish telegraphic communication between Paris and the provinces by sending strong electric currents into the River Seine, at the nearest approachable point outside the German lines. He suggested that, by means of a metal plate sunk in the river, these currents could be received in Paris with a delicate galvanometer.

After experimenting successfully between the Hôtel de Ville and St. Denis, another worker, M. d'Almeida, left the besieged city by balloon on 17th December, 1870, and, after some perilous adventures and hair-raising experiences, descended outside the enemy's lines at Champagne. He made his way by Lyons and Bordeaux to Havre, from which place the necessary apparatus was ordered from England. When this reached France, a month later, the Seine was completely frozen over, however, and before a thaw set in an armistice was arranged. On the conclusion of the peace treaty all interest in the project was lost and the scheme was abandoned.

V

Mention must be made of one other remarkable worker—Mahlon Loomis, an American dentist, whose plan caused some considerable excitement in America at the time. In 1872 he proposed to draw electricity from the higher atmosphere and to use the current so obtained for telegraphic purposes. Loomis based his proposal on the theory that the earth's atmosphere is charged with electricity, the strength of which increases with the height. He assumed that this atmospheric electricity could be drawn off from any particular stratum without the balance being immediately restored by a general redistribution of electricity from the adjacent strata. He proposed to use this fact as a basis of his aerial telegraph, tapping the electricity at any one point of a stratum and so causing a corresponding fall in the electrical density at any distant point of the same stratum.

The following is extracted from his (American) patent, dated 30th July, 1872:

> "The nature of my discovery consists in utilizing natural electricity and establishing an electrical current or circuit for telegraphic and other purposes without the aid of wires, artificial batteries, or cables, and yet capable of communicating from one continent of the globe to another.
>
> "As it was found possible to dispense with the double wire (which was first used in telegraphing), making use of but one, and substituting the earth instead of a wire to form the return half of the circuit; so I now dispense with both wires, using the earth as one-half the circuit and the continuous electrical element far above the earth's surface for the other half. I also dispense with all artificial batteries, but use the free electricity of the atmosphere, co-operating with that of the earth, to supply the current for telegraphing and for other useful purposes, such as light, heat, and motive power.
>
> "As atmospheric electricity is found more and more abundant when moisture, clouds, heated currents of air, and other dissipating influences are left below and a greater altitude attained, my plan is to seek as high an elevation as practicable on the tops of high mountains, and thus establish electrical connection with the atmospheric stratum or ocean overlying local disturbances. Upon these mountain-tops I erect suitable towers and apparatus to attract the electricity, or, in other words, to disturb the electrical equilibrium, and thus obtain a current of electricity, or shocks or pulsations, which traverse or disturb the positive electrical body of the atmosphere between the

two given points by connecting it to the negative electrical body of the earth below."

Loomis experimented in West Virginia, selecting for the purpose two lofty mountain peaks about ten miles apart. From here he sent up two kites, connected to the ground by fine copper wires. To one wire he connected an electrical detector and to the other a switch that, when closed, earthed the wire. We are told that the experiment was successful, and that messages were sent and received by making and breaking the earth connection. Nothing definite resulted, however, and numerous notes appeared in the American press during the next few years. One of these (copied by the *Electrical Review*, 1st March, 1879) stated that Loomis claimed that "with telephones in the aerial circuit he can converse a distance of 20 miles".

From the various editorial comments on Loomis's plan it would seem that the technical press never took the proposal very seriously, as is illustrated by the following typically humorous story from the New York *Journal of the Telegraph* (15th March, 1877):

> "The never-ending procession of the would-be inventors—who from day to day haunt the corridors and offices of the Electrician's Department at 195, Broadway, bringing with them mysterious packages tied up in newspaper—was varied the other day by the appearance of a veritable lunatic. He announced that the much-talked-of great discovery of a few years ago, aerial telegraphy, was in actual operation right here in New York. A. M. Palmer, of the Union Square Theatre, together with one of his confederates, alone possessed the secret, he said. They had, unfortunately, chosen to use it for illegitimate purposes, and our visitor felt it to be his solemn duty to expose them. He explained that with a $60,000 battery they transmitted the subtle fluid through the aerial spaces, read people's secret thoughts, and even knocked them senseless in the street. They could burn a man to a crisp, miles and miles away, and he no more knew what had hurt him than if he had been struck by a flash of lightning—as indeed he had! The object of our mad friend in dropping in was merely to ascertain how he could protect himself from Palmer's illegitimate thunderbolts.
>
> "At this point in the peroration our legal expert lifted his eyes from *Curtis on Patents* and remarked, 'Now I'll tell you what you'll do. Bring a suit against Palmer for infringement of Mahlon Loomis's patent. Here it is—No. 129971. That'll fix Palmer!'
>
> "But the madman protested that this would take too long, and

meanwhile he was in danger of his life every minute. He casually remarked that it had occurred to him that by appearing in the streets in a robe of pea-green corded silk, gutta-percha boots, and a magenta satin hat with a blue glass skylight in the top of it, he might be effectually protected from injury during his daily perambulations!"

We may quite imagine that the harassed American editor was disposed to agree. Whether or not the madman ever appeared in public in this extraordinary costume, the story does not say!

In conclusion, it may be of interest to note that it is recorded that M. Child, of the London Telegraph Training College, successfully repeated Loomis's experiment in 1909. During a heavy hailstorm he used the induced static charge on an aerial, which charge was produced by a dense black cloud overhead, and succeeded by its aid in signalling a distance of three miles (to Charminster). The aerial was 180 ft. in height, and was raised to a potential of some 25,000 volts for five or six minutes.[1]

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[1] *Wireless Weekly*, 30th May, 1923, p. 490.

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CHAPTER VII

ALEXANDER GRAHAM BELL INVENTS THE TELEPHONE

UP to this time the telegraph needle, the galvanometer, or the electroscope—the only known means of registering electrical signals—had necessarily been used in all experiments in wireless. In 1876, however, Alexander Graham Bell invented the telephone, the introduction of which greatly facilitated research in wireless communication. Much of the present-day success of radio-telephony rests with Bell's pioneer accomplishments in wire-transmitted speech.

Steinheil had said that telegraphy without wires would be possible only when we had " the means that could stand in the same relation to electricity that the eye stands to light ". Now, although Bell's telephone did not entirely fulfil this requirement, it is difficult to estimate its importance as far as the development of wireless is concerned, for it placed in the hands of scientists a marvellously delicate instrument, infinitely more sensitive than any apparatus previously employed. It was, indeed, found to be considerably more sensitive even than the mirror galvanometer, which previously had been employed to detect minute currents. Professor Pierce, of Providence, Rhode Island, found that the Bell telephone was capable of giving audible signals with only 1/100,000th part of the current of a single Leclanché cell.

Alexander Graham Bell (*b*, Plate VIII) was born in Edinburgh on 3rd March, 1847. Both his father and his grandfather had attained some distinction as teachers of the deaf and dumb. His father, Alexander Melville, devoted his life to a study of articulate speech, and perfected a system of visible speech, or " lip-reading " as it is sometimes called, for deaf mutes.

" In the boyhood of my three sons," he wrote, " I took them to see the speaking machine constructed by Herr Faber, and we were all greatly interested in it professionally. To test their theoretical knowledge and their mechanical ingenuity, I offered a prize to the one who should produce the best results in imitation of speech by mechanical means. All, of course, set to work, but nothing of startling novelty was devised. The scheme of my second son, A. G. Bell, was, however, the best. Alexander was then only fifteen years of age and he made an artificial skull of gutta-percha that would pronounce weak voice tones when blown into by a hand bellows."

Young Bell attended the Edinburgh High School, proceeding later to the Universities of Edinburgh and London. His father had previously visited America in connection with his system of visible speech, and when he removed to that country (in 1870) he was accompanied by Alexander, who at that time was threatened with a serious illness. When Alexander was 24 years old he realized that only one field of endeavour could make him happy—invention—and now an entire world is grateful for the forces that influenced the direction of this mind into such useful channels. He lived to see many of his prophecies realized.

In 1871 he was appointed Professor of Vocal Physiology at Boston University, but later he established his own school, where he taught his father's system of visible speech. At this time he is described as being " a tall, slender, quick-motioned man with a full face, black side-whiskers and drooping moustache, big nose, and high sloping forehead, crowned with bushy, jet-black hair ". He lived at Salem with a family named Sanders, and in his spare time he experimented with tuning-forks, magnets, and electrical batteries in the cellar of their home. When in London he had learned from Sir Charles Wheatstone that Helmholtz, the German physicist, had successfully reproduced the vowels with unmistakable clearness by vibrating tuning-forks by means of electro-magnets.[1]

This information gave Bell the idea of a musical telegraph. " Why cannot a vibrating reed or fork be made to vary an electric current so as to reproduce sound ? " he asked. " Should it not be possible to send as many messages over a single wire as there are notes on a piano ? " With this idea before him he worked for three years, and in 1874 evolved what he called the " harmonic telegraph ", a device for sending ten or twelve Morse signals over a single wire at the same time, by utilizing a peculiar phenomenon known as sympathetic vibration.

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[1] Apparently Bell was unaware of the discovery (in 1837) of his countryman Page that a musical sound issues from the core of an electro-magnet whenever contact is made or broken between its coil and a battery. Also of the work of J. P. Reis, in Germany, who (in 1861) devised an electrical instrument that transmitted not only music but vowel sounds.

Once having established the principle, Bell worked with a will to develop what he called the " talking telegraph ". He sought to make speech visible, so that the deaf might see its effects on a vibrating needle, thus making sound visible in the vibrations of the needles. His idea was that by studying the vibrations, the deaf could come to understand what sounds they represented, and thus could *see* what was said to them. The two needles vibrating in unison set his mind working in another direction, however, and well it was for humanity that this was the case.

Bell knew that when sound waves fall upon the drum of the human ear they cause the membrane to vibrate in a similar manner to that of his magnetic needles, for he had shortly before worked out the experiment with the help of a dead man ! At the back of the dead man's ear Bell placed a straw, one end of which rested on the ear-drum and the other on a piece of smoked glass. Bell shouted into the ear and the drum in vibrating caused the straw to record the vibrations on the smoked glass. " Why should not a vibrating iron disc set an iron rod or an electrified wire into vibration ? " he asked. " If I can make a deaf-mute talk I can make iron talk."

He visited Joseph Henry, and by him was encouraged to pursue the subject with even greater determination. He found that the path of the inventor is far from smooth, however, and his friends laughed at the idea. He had resigned his professorship at Boston in order to carry out his experiments, and only two private pupils remained. In his experiments he had been financed by Sanders and Hubbard, but they threatened to withdraw their support unless he reverted to his original idea for a musical telegraph. To crown all, his prospective father-in-law announced that he would refuse to allow the marriage to take place unless Bell abandoned " this foolish telephone ".

II

It is a surprising fact that Bell made his crowning achievement of transmitting sounds over wires through the result of an accidental misadjustment of his musical telegraph. This happened on the afternoon of a hot summer's day (2nd June, 1875) in a little room over Williams' Electrical Shop, at 109, Court Street, Boston; Bell and Watson, the latter an apprentice, were experimenting, and Watson subsequently described the discovery as follows:

> " We were hard at work on the same old job, testing some modification of the instruments. Things were badly out of tune that afternoon in that hot garret, not only the instruments, but, I fancy, my enthusiasm and my temper, although Bell was as energetic as ever. I had charge of the transmitters as usual, setting them squealing one after the other, while Bell was re-tuning the receiver springs one by one, pressing them against his ear. One of the transmitter springs, to which I was attending, stopped vibrating and I plucked it to start it again. It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then he came with a rush, demanding:
>
> " 'What did you do then? Don't change anything. Let me see!'
>
> " I showed him. It was very simple—the make-and-break points of the transmitter spring I was trying to start had become welded together, so that when I snapped the spring the circuit had remained unbroken while that spring of magnetized steel, by its vibration over the pole of its magnet, was generating that marvellous conception of Bell's—a current of electricity that varied in intensity precisely as the air was varying in density within hearing distance of that spring. That undulatory current had passed through the connecting wire to the distant receiver, which, fortunately, was a mechanism that could transform that current back into an extremely faint echo of the sound of the vibrating spring that had generated it. What was even more fortunate was that the right man had that mechanism at his ear during that fleeting moment and instantly recognized the transcendent importance of that faint sound thus electrically transmitted."

We can imagine the young scientists' excitement when they realized that the dream of telephonic speech was within the bounds of possibility!

Although the principle had thus been discovered and success was now only a matter of detail, no less than forty weeks' hard work was necessary before the first telephone was made. The first instrument, made by Watson under Bell's directions, was made by mounting over one of the receivers a small drumhead of gold-beaters'-skin, the centre of which was joined to the free end of the receiver spring. The idea was to force the steel spring to follow the vocal vibrations and generate a current of electricity that would vary in intensity as the air varies in density during the utterance of speech sounds. Watson had the instrument ready for trial by the next day. "I made every part of that first telephone myself," he has said, "but I didn't realize while I was working on it what a tremendously important piece of work I was doing."

On the 10th March, 1876, Bell's efforts were crowned with success. On this memorable day a line had been carried down two flights of steps from the attic to the ground-floor and the first test made. Bell could not hear Watson, although he was shouting as loudly as he could, but Watson could hear Bell's voice, and distinguished the words: "Mr. Watson, please come here, I want you!"[1] These were the first words spoken over a telephone, and as Watson has said: "Perhaps if Mr. Bell had realized that he was about to make history, he would have been prepared with a more sounding and interesting sentence".

In after years, when Bell told the simple story of the origin of the telephone, he liked to add that after English, the Japanese language was the next to be sent over the telephone. "I had two Japanese students," he said. "One of them asked me if the telephone could speak Japanese. I told him to try!"

It is sometimes said that "thought is infectious", and in the invention of the telephone we have another of those strange coincidences occasionally met with in scientific discovery. Although the scientific world had waited for many years for such an invention it is a remarkable fact that, on the morning of 14th February, 1876, two men almost simultaneously patented a telephone. Bell filed his specification at the United States Patent Office on the morning of that day, and a few hours later Elisha Gray applied for protection for his design for a similar contrivance. Neither knew that he had a rival, and even more remarkable than the coincidence of date is the fact that the respective particulars were entered at the same office !

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[1] On 25th January, 1915, Bell and Watson played an important part in opening the U.S.A. trans-Continental line, the construction of which was a great triumph of telephone engineering. Over 3,390 miles in length and containing 2,960 tons of copper, the line is supported by 130,000 poles across thirteen States. Bell, in New York, spoke in exact reproduction of the original occasion to Watson, now in San Francisco: "Mr. Watson, please come here, I want you." To this Watson answered: "It would take me a week now!"

III

Experiments proceeded apace until (on 9th October, 1876) Bell held the first recorded long-distance telephone conversation. He spoke to his assistant, Watson, over a telegraph line between Cambridge and Boston (U.S.A.). Soon after this achievement the Boston *Globe* transmitted the first press report from Salem, Mass., to Boston, by telephone. Despite these results the public remained unmoved and even politely incredulous. Remarkable though it now seems, Bell was quite unable to interest anyone in his invention. Often on approaching business men they turned him away, saying that they had no time to bother with him or his " fool talking-machine ".

At the Centennial Exhibition, held in 1876 at Philadelphia, Bell and his invention were placed in a remote corner of the Educational Building, and here the telephone was shown for six weeks without attracting any attention. Dom Pedro, the young Emperor of Brazil, was visiting the Exhibition with a number of courtiers, and catching sight of Bell exclaimed : " Professor Bell, I am delighted to see you again ! " The exhibition judges, who had stood listlessly by, laughingly discussing " this new toy ", were surprised to find the young pale-faced inventor hailed by an Emperor, and stood deferentially around to see what would happen next. It appears that the Emperor had been greatly interested in Bell's humanitarian work in connection with the deaf and dumb, and on an earlier trip had visited his classes at Boston University with a view to founding similar classes at Rio de Janeiro. Bell explained his invention and, asking the Emperor to place the receiver to his ear, went to the transmitter at the other end of the hall. None of the judges or courtiers knew what was about to happen, and we can well picture their astonishment when the Emperor suddenly cried, " My God! it speaks!" Lord Kelvin (then Sir William Thomson) followed the Emperor at the receiver, and declared " It does speak! It is the most wonderful thing I have seen in America!" One after another the judges listened at the receiver, and all expressed their wonder and amazement at the genius of the young teacher of deaf mutes. The telephone was brought from its obscure corner and given the most prominent place in the Exhibition, and Bell became famous in a night. The incident of the Emperor and the telephone caught the popular fancy and drew more attention to the invention than all Bell's efforts with business men.

Even then the public would not regard the telephone seriously, however, preferring to regard the invention as a scientific curiosity. Under the management of Hubbard, Bell and Watson gave lectures, with practical demonstrations. The first lecture was given at the Essex Institute at Salem, Bell appearing before the audience and Watson supplying the transmissions from the laboratory in Boston. After Bell had described the invention, music from the laboratory was transmitted over a telegraph wire and songs were sung by Watson himself, to the delight of the audience, who thus experienced broadcast transmissions for the first time.

It was not until sixteen months after Bell had filed his patent specifications, however, that the first telephone company was established. This was in August, 1877, when there were already 778 telephones in use. The Bell Telephone Association had no capital at the outset, and only four shareholders—Bell, Hubbard, T. A. Watson, and Thomas Sanders—who between them furnished all the financial backing. Progress was slow, commencing with the installation of a few burglar alarms, followed by small exchanges at New York, New Haven, Bridgeport, and Philadelphia. Then one of the Wall Street clients of the Western Union decided to replace the Morse telegraphs with Bell telephones. Bell had some time previously offered his invention to the Western, but it had been contemptuously rejected. Now the Western formed a rival concern, " The American Speaking Telephone Company ", but Bell took legal action and won a decisive victory, the result of which was to send the Bell shares up to one thousand dollars each. Bell, Watson, and Sanders sold out their interests at this point and received a comfortable fortune, whilst the commercial development of the telephone passed to other hands.

It is interesting to learn that Bell's patent has been described as "the most valuable single patent ever issued". Bell and his company had to contest over 600 actions, many of which were bitterly prolonged by aspirants to prior claims to the great invention, but Bell's rights were always upheld by the courts, the incontestable answer to all claims being that no one but Bell had produced a talking telephone. His most dangerous opponent was Elisha Gray, whose partner once said: "Of all the men who didn't invent the telephone, Gray was the nearest!"

IV

About the end of the year 1876, Bell for the first time used the telephone, instead of a galvanometer, to trace out the lines of the earth's potential. It is interesting to learn that it was in the course of these experiments that he "added a steel-band to the telephones, to clasp the 'phone to my head, leaving my hands free".

Describing these researches, he said:

> "Using two metal exploring rods—they were really stove pokers—I set to work on Mr. Hubbard's place on the outskirts of Cambridge and drove the rods into the ground. At the receiving rod I found that upon listening with the telephone I could hear a clock ticking. I then noted that at periodic intervals the clock would miss a tick. By means of that irregularity I was able to identify the clock as the time clock of the Cambridge University, a half-mile away. There was, I knew, a telegraph line from the Observatory to Boston, to signal the time. Using ground that was charged, with the Observatory as the centre of an imaginary circle, I was able to define concentric circles that indicated, much more accurately than has been possible with a galvanometer, the lines of potential. In other words, if both the rods were in a part of the charged ground that was to be designated as concentric circle 9 closest to the Observatory, both ends of my earth telephone circuit had the same potential; but if one were in 9 and another in 8, there would be a residual effect and I would get a sound."

He has also described how he subsequently carried out similar experiments in a different direction :

> " First, in a vessel of water I placed a sheet of paper. At two points of that paper were fastened two ordinary sewing needles, which were also connected with an interrupter that interrupted the circuit about one hundred times a second. Then I had two needles connected with a telephone : one needle I fastened on the paper in the water, and the moment I placed the other needle in the water I heard a musical sound from the telephone. By moving the needle around in the water, I would strike a place where there would be no sound heard. This would be where the electric tension was the same as in the needle ; and by experimenting in the water you could trace out with perfect ease an equipotential line around one of the poles in the water."

Bell thought that these small-scale experiments could be repeated on a large scale with the same degree of success and that a method of communicating electrical signals between vessels at sea might be evolved, based on the principles underlying the experiment. In July, 1877, he sailed for England on his honeymoon, having married Mabel Hubbard, daughter of Gardiner Hubbard, a noted lawyer of Boston, who subsequently played a considerable part in the commercial success of the telephone.

In London, Bell made a classic speech (31st October, 1877) before the Society of Telegraph Engineers, in the course of which he said :

> " When we sing with a piano certain of the strings of the instrument are set in vibration sympathetically by the action of the voice with different degrees of amplitude, and a sound, which is an approximation to the vowel uttered, is produced from the piano. Theory shows that, had a piano a very much larger number of strings to the octave, the vowel sounds would be perfectly reproduced. My idea was to use a harp-like apparatus and to throw certain of the rods into vibration by sounds of different amplitude. On the other end of the circuit the corresponding rods of a second harp would vibrate with their proper relations of force, and the timbre of the sound would be reproduced. The expense of constructing the apparatus deterred me from making the attempt, and I sought to simplify the apparatus before having it made." [1]

Queen Victoria's first impression of the telephone is recorded in the second series of her letters :

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[1] Prescott : *The Speaking Telephone* (1878).

> Osborne,
> 14*th January,* 1878.
>
> After dinner we went to the council room and saw the telephone. A Professor Bell explained the whole process, which is most extraordinary. It had been put in communication with Osborne Cottage, and we talked with Sir Thomas and Mary Biddulph; also heard some singing quite plainly. But it is rather faint, and one must hold the tube close to one's ear.

The Queen was so interested that she wished to purchase the instruments and wires which had been used. Bell, however, offered a set of telephones made expressly for her use.

V

Whilst in London, Bell experimented across the Thames on similar lines to the plans of Morse, Lindsay, and others.

> "On one side", he said, "I placed two metal plates at a distance from each other, and on the other two terminals connected with the telephone. A current was established in the telephone each time a current was established through the galvanic circuit on the opposite side, and if that current was rapidly interrupted you would get a musical tone."

Returning to America, he described these experiments before the American Academy of Arts and Sciences in Boston, on 11th December, 1878. Professor Trowbridge urged him to make further experiments, the first of which were carried out on the Potomac.

> "In the experiments on the Potomac", Bell said, "I had two boats. In one boat we had a Leclanché battery of six elements and an interrupter for interrupting the current rapidly. Over the bow of the boat we made water connection by a metallic plate, and behind the boat we trailed an insulated wire, with a float at the end carrying a metallic plate so as to bring these two terminals about 100 ft. apart. I then took another boat and sailed off. In this boat we had the same arrangement, but with a telephone in the circuit. In the first boat, which was moored, I kept a man making signals; and when my boat was near his I would hear those signals very well—a musical tone, something of this kind: 'tum-tum-tum.' I then rowed my boat down the river, and at a distance of a mile and a quarter, which was the furthest distance I tried, I could still distinguish those signals."

One of the boats that he used was then floating near Chain Bridge, while at the conclusion of the experiments his own boat was at the Washington Monument.

Bell pointed out at the time the practical utility of his experiments, since " most of the passenger steamships have dynamo engines and are electrically lighted ", and each vessel could trail a wire a mile or so in length electrically charged from the dynamo, the end on board being attached to a telephone.

> " Then ", he said, " your dynamo or telephone end would be positive and the other end of the wire trailing behind would be negative. All the water about the ship will be positive within a circle whose radius is one-half the length of the wire. All the water surrounding the trailing end will be negative within a circle whose radius is the other half of the wire. . . . It will be impossible for any ship or object to approach within the radius of the water so charged in relation to your ship without the telephone telling the whole story to the listening ear. Now, if a ship coming in this area also has a similar apparatus, the two vessels can communicate with each other by their telephone. If they are enveloped in a fog, they can keep out of each other's way. The matter is so simple that I hope our ocean steamships will experiment with it."

Since those early days of electrical experiment it has become increasingly apparent that the relationship of earth characteristics to transmission in both line telegraphy and telephony and in wireless must sooner or later have been given just such attention as Bell and others gave to it. The experiments of these pioneers made possible many improvements and developments in earth telegraphy, including one of the chief systems used during the war both by the Allies and the Germans for intercepting messages, particularly telephone messages. Because ground methods of transmission do not permit of the use of high frequencies and as they do not employ tuned circuits, they cannot, in view of the many authorities, be included in the sphere of modern wireless. Nevertheless, the experiments of the pioneers with ground and water telegraphy and telephony might have led to results that have not even yet been attained, if Bell had continued his researches in this direction.

Although the introduction and development of the telephone was one of the greatest triumphs of the twentieth century, Dr. Bell was never interested in the subsequent expansion of the commercial side of his invention. This was left to others to develop, and almost before the first telephones were being manufactured the inventor had struck off into new fields. "It has always been that way," he said; "after I have made a discovery and get it under way, my interest in it lessens."

It is amusing to hear that towards the close of his life Dr. Bell found the telephone such a source of annoyance that he had it removed from his room.

VI

"*Mr. Bell! Mr. Bell! If you hear me, come to the window and wave your hat!*" Four years after the first transmission of the human voice over a telephone wire, Dr. Bell heard (on 15th February, 1880) these words—the first ever spoken over a wireless telephone. The voice was that of Charles Sumner Tainter, and he was speaking from the top of the Franklin School in 13th Street, Washington, to Bell in his laboratory near 14th Street. The means by which the transmission was effected was a beam of light, the whole apparatus being subsequently known as the "Photophone".

Though credit for its invention is generally given to Bell, it must be mentioned that at least two other inventors had suggested, if not actually made use of, a similar means of telephony without wires. One of these was Steinheil, whose pioneer work in connection with wireless has already been dealt with. In his classic paper *Telegraphic Communication Especially by Means of Galvanism*, Steinheil had said:

> "Another possible method of bringing about transient movements at great distance, without any intervening artificial conductor, is furnished by radiant heat when directed by means of condensing mirrors upon a thermo-electric pile. A galvanic current is called into play, which in its turn is employed to produce declinations of a magnetic needle. The difficulties attending the construction of such an instrument, though certainly considerable, are not in themselves insuperable. Such a telegraph, however, would only have this advantage over those [semaphores] based on optical principles—namely, that it does not require the constant attention of the observer; but, like the optical one, it would cease to act during cloudy weather, and hence partakes

of the intrinsic defects of that instrument [the semaphore]. This method therefore is not probably able to stand a comparison with others." [1]

In his paper Steinheil reviews three principles by which he considers telegraphic communication might be established—by light, radiant heat, and the propagation of sound. These three principles, he points out, " have this in common—they do not require that there should be a direct connection between the two stations. The air, water, and the ground form the natural conductors of the conditions excited or rendered available, and which serve for making the communications. In this essential circumstance they differ advantageously from other feasible plans. . . ." [2]

In 1878 A. C. Brown, of the Eastern Telegraph Company, submitted plans for a photophone to Dr. Bell, who afterwards said of them : " To Mr. Brown is undoubtedly due the honour of having distinctly and independently formulated the conception of using an undulatory beam of light, in contradistinction to a merely intermittent one, in connection with selenium and a telephone, and of having devised apparatus—though of a crude nature—for carrying it into execution." [3]

Bell's " Light Phone ", as he first called it, was exhibited at both the Louisiana Exposition and the World's Fair, where it was described as the " Radiophone ". The instrument was based on the fact (discovered by May, one of Willoughby Smith's assistants, and contemporaneously by Siemens, in 1872) that under certain conditions selenium possesses the property of offering a greater resistance to an electric current when in the dark, than is the case when it (selenium) is under a ray of light.[4] In collaboration with Sumner Tainter, Bell extended his researches and found that several other substances are also sensitive to light, including iron, silver, gold, ivory, wood, mica, glass. None approaches the sensitivity of selenium, however, which alters its resistance to the passage of an electric current under the influence of light of rapidly varying intensity.

[1] Sturgeon : *Annals of Electricity* vol. iii, p. 445.

[2] Ibid.

[3] *Journal, Institution of Electrical Engineers*, vol. ix, p. 404.

[4] " Selenium, indispensable to this apparatus, was discovered by Berzelius in 1817. It is a metalloid resembling tellurium ; they differ, however, in electrical properties. Tellurium is a good conductor, selenium in its usual forms is a non-conductor. Knox, in 1837, discovered that selenium is a conductor when fused ; in 1851, Hittorf showed that it conducts when in one of its allotropic forms. . . ."—A. G. Bell, in the *Proceedings*, American Association for the Advancement of Science, 1880.

Bell's photophone relied on a ray of light falling on selenium connected to a battery, with a telephone receiver in the circuit. He developed a mirror of minimum thickness in the shape of a telephone diaphragm. Fastened to this was a mouthpiece, speech through which caused the mirror to vibrate. A beam of light was then thrown against the mirror, and, by reflection, was directed to the receiving apparatus. The vibrations of the mirror caused fluctuations in the light rays and corresponding variations in the amount of light thrown upon the selenium cell. So delicate is its action that every sound, indeed every word, is faithfully reproduced. For instance, the word " Hello " causes changes in an electrical circuit distinctly different from those made by the words " Good-bye ". The vibrations of the mirror cause minute fluctuations in the rays of light, and under their influence the receiving apparatus sends out sounds that reproduce the word " Hello ".

In addition to selenium, Bell also experimented with vegetable fibre lamp-black placed in a glass bulb. He demonstrated that many other substances could be used, such as black worsted cloth, silk, or particles of rubber. He found that the action of the rapidly varying degree of heat in the light rays falling on these substances caused them to expel and absorb gases, alternately. These gases in turn produced vibrations in the air in the bulb in which they were enclosed, and rubber tubes fitted with earpieces enabled the listener to hear an exact reproduction of the words spoken at the transmitter.

Experiments with the radiophone were carried out between the top of the Franklin School and the Virginia Hills, a mile and a half away, until they were successful. Bell then placed all the records into a sealed envelope, which he deposited in the Smithsonian Institution, where it is believed the envelope still remains unopened. Shortly after this had been done H. E. Lix, of Bethlehem, Pennsylvania, claimed to have invented a method of seeing by telegraph. The two ideas of the mystery of the sealed envelope and an invention by an unheard-of inventor became confused in the newspapers, with the remarkable result that two English inventors assailed Bell for seizing their ideas concerning an instrument by which one could see by telegraph !

VII

Subsequently, further experimental work was done on the radiophone by the American Telephone and Telegraph Company. In the course of some of the experiments arc lights were used, and in April, 1897, Hammond B. Hayes, one of the company's engineers, noticed a humming sound, audible in the receiver of the radiophone. This sound corresponded in pitch with that produced by the generator supplying the current for the arc lamp used in the experiments. Hayes concluded that if the words spoken into a telephone were made to act directly upon the lighting circuit, it would not be necessary to use the mirror employed by Bell, and the distance over which speech could be transmitted would be greatly increased. In other words, the telephone current could be superimposed upon the lighting current by connecting the telephone wires to the wires in the arc circuit. This device was patented in June, 1897, and subsequent improvements enabled the voice to be heard with distinctiveness at points several miles from the transmitter.

Bell's radiophone system is to-day known as the "Photophone", and in a further improved form it was demonstrated at the 1923 meeting of the British Association at Liverpool. In its most recent form the original principles are followed, the receiver consisting of a selenium cell enclosed in a small glass bulb. In making the cell, very fine brass wires, covered with a thin layer of selenium, are wound upon Indian pipe-stone and the wires connected to the telephone receiver. The rays of the lamp at the transmitting station are then concentrated upon the selenium at the receiving station by a reflector.

The transmitting apparatus depends on a searchlight such as is used on warships. From the telephone transmitter wires lead to the lamp and are attached to the wires carrying the lighting current. Words spoken into the transmitter cause the rays of the searchlight to fluctuate, but to an extent that is imperceptible to the eye of an onlooker. Although the receiver may be miles away and out of sight, the selenium responds to these minute fluctuations in the light rays, causing alterations in the current in the receiving circuit in thousands of infinitesimal changes. So wonderfully does the selenium respond that not only are the spoken words reproduced but the actual tones of the voice of the speaker !

The use of the photophone is limited to clear skies, and although it may be used in the daytime as well as at night, it cannot be used in a fog. It has been used successfully by the German Government for lighthouse work and by the U.S. Signal Corps. One of its principal advantages is its absolute secrecy, for the conversation cannot be tapped.

VIII

Dr. Bell was a remarkable man and throughout his long life retained his wonderful enthusiasm for scientific research and study. He recorded his daily experiments and speculations in a kind of diary, which at the time of his death consisted of a score of volumes, each of five hundred pages and packed with the thoughts of an intellectual life in a variety that is incredible.

It has been said that a true sign of genius is versatility, and if this is an accurate observation, Dr. Bell was no exception to the rule. In these volumes his tremendous energies are devoted to the telephone ; to kites ; to the scientific breeding of sheep ; to the utilization of waste heat ; the necessity of accepting a metric system ; experiments in preserving food ; notes on eugenics and the biological history of a cat ; oral teaching ; the utility of action and gesture ; observations on lip-reading ; on Hertzian waves ; the first of all wireless telephones, the photophone, and a hundred other subjects, not to mention many pages devoted to glorifying Life in general, and to his early experiments in transmitting wireless signals through the earth and through the waters of the Potomac. He also found time to interest himself in the problems of mechanical flight. In the days when aviation was in its infancy, he contributed valuable work in the attempt to conquer the air.

In looking back over his career we cannot fail to realize the greatness of his work and of all that he has done for the world. Not only did he, as an inventor, " dream dreams ", but he lived to see his dreams come true. A word-picture of him, drawn in the autumn of his life, shows us a majestic figure—a strong commanding type of a man—tall and finely built, moving amongst a happy family group. His skin tanned by the open air, his thick white hair flung back, he still possessed the clear blue eyes of a young man.

This great man, benefactor of hundreds of thousands, died in the early hours of 2nd August, 1923, at his home on his estate near Baddeck, Nova Scotia. He was in his 76th year, and each year from the 24th had been devoted to science. He took particular pride and pleasure in inventing devices to alleviate the sufferings of humanity or to shorten their labours. At his own request he was buried in a grave at the crest of Beinn Breagh Mountain, a spot that surely will be a shrine where thousands will pay homage to one whose name will live as long as civilization remains.

WORKING MEN'S COLLEGE LIBRARY.

CHAPTER VIII

PIONEERS OF SIGNALLING WITHOUT WIRES BY INDUCTION; J. W. WILKINS SUGGESTS SIGNALLING TO FRANCE BY INDUCTION; TROWBRIDGE'S PLAN FOR TRANSATLANTIC WIRELESS AND FOR SIGNALLING TO SHIPS AT SEA

IT is the fate of many workers that their suggestions and inventions—even though practical enough—do not always see the light of day at the time of their inception. In many cases this is not due to any fault of the inventor himself, who is often the victim of adverse circumstances and has neither the means nor the friends with which to back-up his work. In these cases, as often as not, the invention is cast aside and forgotten. Sometimes, years afterwards, another worker in the same field stumbles across the same idea as the original inventor, or evolves a similar device. In these circumstances he is naturally greatly perturbed when he finds that he has been forestalled, or is chagrined to find an indignant inventor accusing him of piracy!

> "It is not to be expected", wrote J. W. Wilkins, dealing with this subject, "that everyone shall get to know what everyone else has done in any particular direction, especially when many years have elapsed, and perhaps before they were born, or could read for themselves, or ever were in a position to see the accounts of what others had done in print. This holds good with reference to a form of instrument I claimed in . . . 1849. . . . The same design has been patented at least twice in the United States, the last time within a year or two, and illustrated and described as a new invention in the pages of the *Electrical Engineer* of New York. How was that last patentee, or the patent officials at Washington, to know that the *invention* under consideration was common property, and was well known to scores of persons in the United States near half a century ago? . . ."[1]

Almost every branch of science has many such instances, andwireless is no exception.[1] In the New York *Electrical Engineer* of 29th May, 1895, a claim was made that in 1880 Professor Trowbridge was the first to telegraph without wires by induction. The claim was, as a matter of fact, disputed by J. W. Wilkins.[2] To his pioneer work in this connection Sir Charles Bright, of Atlantic cable fame, paid a tribute, characterizing it as " the earliest recorded instance of a worked-out method of telegraphy without wires—or, rather, inductive telegraphy ".[3]

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[1] *The Electrician*, 21st June, 1895.

John Walker Wilkins (*a*, Plate IX), " who erected the first telegraph line in the world ", was born at Hampstead on 25th March, 1827, and died at Kingston-on-Thames in 1913. When only eighteen years of age he was appointed resident superintendent of the Northampton and Peterborough telegraphs on the opening of the line on 1st July, 1845, having previously been under the personal training of W. F. Cooke for three months " in the establishment of Robert Reid, the original maker of telegraphs ". He then entered the service of Cooke and Wheatstone, who were afterwards incorporated as the Electrical Telegraph Company of the early telegraph days, and it was in this way that he received his first appointment. A few months after this appointment, which was the first of the kind on any railway in the country, he became general superintendent of all the railway telegraph lines that

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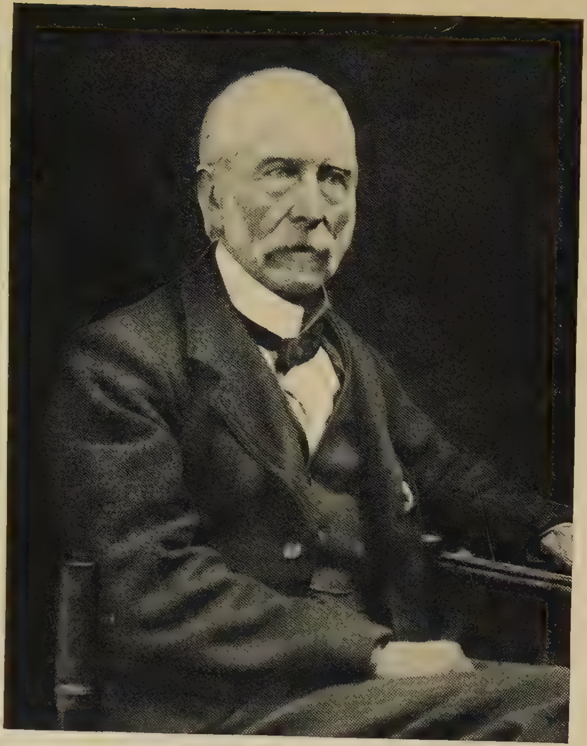
[1] Such an instance, the mention of which is particularly appropriate at this point, was the electro-magnetic relay invented by J. W. Wilkins, with whose work we are next to deal. In 1851 Wilkins went to America to assist O'Reilly, a concessionaire under the Morse patents. Disputes arose between Morse and O'Reilly, but Wilkins came to the rescue with his relay, which was independent of the Morse patent, and for the time O'Reilly was saved. But in the end Morse was too strong for him, and the Wilkins relay was dispensed with and its principle and existence soon forgotten. Forty-three years later Weston brought out an identical instrument and claimed it to be his original invention !

[2] In this connection Wilkins wrote (in *The Electrician*, 21st June, 1895): " . . . after all, I don't value at one finger-snap the circumstance that I happened, so early as the year 1849, to suggest a possible mode of telegraphing without wires, and of which, most likely, Professor Dolbear was ignorant. It is only the apparatus by which I obtained the signals in experiments I made to this end to which I attach the least importance. In a footnote to my letter which appeared in the *Mining Journal* it will be seen that I laid ' claim ' to a conjunction of coils of wire to convey electricity, with magnets for the purpose of deflecting them, as an original form of ' telegraph ' working with ' the least amount of current and resistance ', and ' depending most upon the power of the magnets ', as a ' design or invention of my own '. Later on I will show why I attach importance to the above."

[3] *The Engineer*, 17th March, 1899.



JOHN WALKER WILKINS
(1827-1913)

AMOS EMERSON DOLBEAR
(1837-1910)

had been erected from Hull to Fleetwood and from Rugby to Newcastle, as well as of the extensions in progress towards Berwick-on-Tweed. On completion of the telegraph line from Rugby to London, connecting the Metropolis with the rest of England, he took charge of that line also, and of the temporary premises off Euston Square, London.[1]

In 1848 the Queen's Speech on the opening of Parliament was for the first time telegraphed to a dozen towns in the Midlands and the North of England for publication in the evening papers. It is interesting to mention that a report of the speech had to be conveyed by special train to Rugby, there being no telegraphs south of Rugby at the time. From Rugby the speech was telegraphed to Derby, repeated to Normanton, from whence a copy was dispatched by train to York, and from here it was re-telegraphed to Newcastle and the north. At York a distinguished gathering assembled to witness what was at that time considered to be little less than a miracle ![2] Wilkins, then only 19 years of age, was responsible for all the arrangements for carrying out this historic event.

The claim that Trowbridge was the first to signal without wires called forth a letter, which appeared in *The Electrician* on 19th July, 1895, from Wilkins, who wrote :

> " Nearly fifty years ago, and thirty years before Professor Trowbridge made ' original researches between the Observatory at Cambridge and the City of Boston ', the writer of these lines had also researched on the same subject. A year or two later he published the results of his investigations in an English periodical—the *Mining Journal* of 31st March, 1849—under the heading ' Telegraph Communication between England and France '. In that letter, after going into the subject very much like the American Professor in 1880, there will be found my explanation—also not differing much from the Professor's—as to how the thing was to be done ; except that, in my case, I proposed a new and delicate form of galvanometer or telegraph instrument for the purpose, while he made use of the well-known telephone. I suggested the erection of lengths of telegraph wires on the English and French coasts, with terminals dipping into the earth or sea, and as nearly parallel as possible to one another ; and I suggested a form of telegraph consisting of ' coils of finest wire, of best conductibility ', with magnets to deflect them, on the passage of a current of electricity

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[1] This house, the first public telegraph office in the world, was the third from the south-eastern corner of the crossing of Seymour Street with Drummond Street.

[2] *G.W.R. Magazine*, February, 1926, p. 53.

through them, which I expected would take place on the discharge of electricity through the circuits on either side of the water; anticipating, of course, that a portion of the current would flow from the one pair of earth-plates—terminals of one circuit—to the other pair of terminals on the opposite shore.

"It may be interesting to relate how I came to think that telegraphy without wires was a possibility, and that it should have appeared to me to have some value, at a time when gutta-percha as an insulator was not imagined or the ghost of a proposition for a submarine wire existed. At that time, too, it was with the utmost difficulty that efficient insulation could be maintained in elevated wires if they happened to be subject to a damp atmosphere.

"It was in the year 1845, and while engaged on the only long line of telegraph then existing in England—London to Gosport—that my observations led me to question the accepted theory that currents of electricity, discharged into the earth at each end of a line of telegraph, sped in a direct course—instinctively, so to say—through the intervening mass of ground to meet a current or find a corresponding earth-plate at the other end of it to *complete the circuit.* I could only bring myself to think that the earth acted as a reservoir or condenser—in fact, receiving and distributing electricity almost superficially for some certain or uncertain distance around the terminal earth, and that according to circumstances only. A year later, while occupied with the installation of telegraphs for Messrs. Cooke and Wheatstone, a good opportunity offered of testing this matter practically upon lengths of wire erected on both sides of a railway. To succeed in my experiment and detect the very small amount of electricity likely to be available in such a case, I evidently required the aid of a very sensitive galvanometer, much more so indeed than the long pair of astatic needles and coil of the Cooke and Wheatstone telegraph, which was then in universal use as a detector. The influence of magnetism upon a wire conveying an electric current at once suggested itself to me, and I constructed a most sensitive instrument on this principle, by which I succeeded in obtaining actual signals between lengths of elevated wires about 120 ft. apart. This, however, suggested nothing more at the moment than that the current discharged from the earth-plates of one line found its way into the earth-plate of another and adjacent circuit, through the earth.

"Later on, I had other opportunities of verifying this matter with greater distances between the lines of wire, and ultimately an instance [presented itself] in which the wires were a *considerable distance apart*, and with no very near approach to parallelism in their situation. Then it was that it entered my head that *telegraphing without wires might be a possibility.*"

The letter in the *Mining Journal* to which Wilkins referred reads as follows, with slight alterations in the phraseology to make the writer's meaning more clear and connected:

"Allow me, through the medium of your valuable journal, to draw attention to a principle upon which a telegraphic communication may be made between England and France without wires. I take for certain (as experiments I have made have shown me) that when the positive and negative poles of a battery are dipped into or connected with any extended conducting medium, the electricity diffuses itself in radial lines between the poles. The first and larger portion will pass in a straight line, as offering the least resistance; the rays will then form a series of curves, growing larger and larger, until, by reason of increasing distance, the electricity following the outer curves is so infinitesimal as to be no longer perceptible. . . .

"These rays of electricity may be collected within a certain distance [focused as it were] by the interposition of a metallic medium that shall offer less resistance than the water or earth; and, obviously, the nearer the battery, the greater the possibility of collecting them. I do not anticipate that the distance of twenty miles is at all too much to collect a sufficient quantity of current to be useful for telegraphic purposes. The quantity would be small, however, and with our present telegraphic instruments would not be detected at all. . . . The current . . . must be detected, not by its amount but by the fact that it does actually exist, however minute may be the quantity. If, then, it is possible, as I believe, to collect in France some portion of the electricity which has been discharged from a battery in England, all that is required is to know how to deal with it so that it shall indicate its presence.

"I suggest the following arrangement. Upon one shore I propose to have a battery that will discharge its electricity into the earth or sea, with a distance between its poles of five, ten, or twenty miles, as the case may be. Then a similar length of wire, having been erected on the opposite coast, as near to, and parallel with it, as possible, has its ends also dipping into the earth or sea. In this circuit is placed an instrument consisting of ten, twenty, or more round or square coils of the finest wire of the best conductibility, suspended on points or otherwise between, or in front of, the poles of an electro, or permanent, magnet or magnets. Any current passing through the coil would be indicated by its moving or shifting its position with reference to the poles of the magnet. This would constitute a receiving apparatus of the most delicate character, for its efficiency would depend not so much on the strength of the current passing as on the power of the magnet, which may be increased as desired.

"I hope some one will take up this suggestion and carry it out practically and to a greater extent than my limited experiments have enabled me to do. Of its truth, for long as well as for short distances, I am satisfied, and only want of means and opportunity prevent me carrying it out myself."

Discussing this early proposal, Wilkins subsequently wrote:

"I will just say that all thought of induction was absent in my first experiments. I modified my views in this respect a year or two later, but I did not attach sufficient importance to the matter to follow up my communication to the *Mining Journal*, especially as at that time a cable was actually laid across the Channel, which I could not doubt would be a success, and a permanent one, too. I rather courted forgetfulness of the proposition. Whatever my opinion at that time was as to the source of the electricity that I discovered in the far-removed and disconnected circuit, the result was the same, and the means I used to obtain it the same in principle as those that make the matter an accomplished fact to-day—viz. elevated lengths of wire, and the discharge of electricity from the one on to a delicate receiving apparatus in the circuit of the other.

"As regards the form of receiving apparatus that I suggested for indicating the signals, I did then, and do now, attach great importance to the happy idea. It happens to be the most delicate form of detector or galvanometer, and is identical in principle with Lord Kelvin's apparatus for long-distance cable working, which, in his Siphon Recorder Patent, he says is as sensitive as his Mirror Galvanometer."[1]

Dealing with the controversy in an editorial, the *Electrician* wrote (22nd November, 1895):

"Little did Professor Dolbear know what he was bringing upon himself when, in the lightness of his heart, he wrote to the *Electrical Engineer* of New York last May to claim for Professor Trowbridge, of Harvard, 'whatever merit and utility' there may be in connection with the origination of 'doing telegraphic work by means of earth conduction'.

"Mr. Preece, so far as we are aware, makes no claim to have been the first to have *thought* of telegraphy without wires. On the other hand, he has certainly been the first to persistently experiment in this direction, and to attain anything approaching practical success. Moreover, judging by the titles of many of his papers and by their contents, he does not think that 'earthed conduction' plays any appreciable part in the matter, pinning his faith to 'induction', though conclusive experiments with two completely metallic thoroughly well insulated circuits are wanting.

"But however this may be, priority in suggesting telegraphy without wires belongs, it would appear, to this side of the Atlantic. That veteran telegraphist, Mr. J. W. Wilkins, states in a letter, to be found in our 'Correspondence' columns this week, that he publicly suggested the idea of wireless telegraphy between England and France so far back as 1849, having previously made some tentative experiments with the aid of a moving-coil galvanometer of his own design.

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[1] Wilkins thus anticipated Lord Kelvin's discovery and also the Deprez-D'Arsonval instrument so much used on the Continent, as well as many other similar instruments largely used in telegraphy.

Mr. Wilkins, we are glad to see, is not inclined to attach overmuch importance to a mere suggestion, even when, as in his case, it had for basis considerable experiment and the invention of a new indispensable form of instrument; neither does he imply, as does Professor Dolbear on behalf of Professor Trowbridge, that his work has been intentionally ignored. As Mr. Wilkins puts it, 'it cannot be expected that everyone shall get to know what everyone else has done in any particular direction'."

II

It is clear that the effects of induction on telegraph wires running on the same poles as the disturbed wires had been noticed certainly before the invention of the telephone,[1] and this instrument had not long been in use before it was found to be peculiarly sensitive to these induced currents. Transmissions that were being sent over nearby parallel wires were picked up by the telephone circuit and faithfully reproduced in the receiver. For instance, Mr. Rathbone, at Albany, New York, had connected a telephone to the telegraph line between his house and the Observatory. One evening (in August, 1877) it appeared to him that there was some unauthorized merriment at the Observatory, for he distinctly heard singing and music over the telephone. He made inquiries, but to his surprise found that the music did not originate at the Observatory. Next day he wrote to the local press about the matter and gave a list of the tunes, which resulted in the discovery that the musical performance was a concert given in New York in connection with some experiments conducted by Edison with his "singing telephone", which, on the evening in question, was connected to a telegraph wire between New York and Saratoga Springs. On the next occasion on which the musical performance was repeated, further observations were made, and the concert was heard as clearly as on the previous occasion. A telephone was then connected in circuit with a wire running from Albany to New York, when the music was heard so loudly that when the telephone was placed in the centre of the room the company seated around could clearly hear it. Between 28th August and 11th September the experiment was repeated on six occasions, and two other experimenters 200 miles distant noted the same effects as those observed at Albany.[1] Concerts given in New York and transmitted over a telegraph wire with earth return for the benefit of listeners in Saratoga, Troy, and Albany were also heard in Providence by Dr. Channing when conversing with a friend a quarter of a mile distant.

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[1] Professor Hughes undertook a series of experiments in this connection at the request of the French Telegraph Administration in 1868, and gave his results in a paper, read before the Institute of Electrical Engineers on 12th March, 1879.

The explanation of these curious effects was found to be as follows. Edison's musical telephone converted sound waves into electric waves at the transmitting station, which waves were reconverted into sound waves at the receiving station. The battery used consisted of 125 carbon-bichromate cells, with 100 to 3,000 ohms resistance interposed between the battery and the line, which extended from the New York Office of the Western Union to Albany. The same poles that carried the wire carried—for 16 miles—four other wires to Providence and—for 8 miles—another wire from Boston to Providence. The wires were all insulated and earthed at New York. At Providence there were six wires running into the Western Union Office from New York and Boston, carried by the same poles—for the last 905 ft.—as a single wire of the American District Telephone, which was not earthed. Thus the music passed by induction from the Albany wire to the parallel New York–Providence line, and from this to the single American District wire at Providence. The extremely minute quantity of the electrical current that was subsequently induced in the third circuit afforded a further instance of the great sensitivity of the Bell telephone.

III

Several scientists experimented with the property that lay at the basis of the curious results just described. Referred to as "bug-a-boo" by Sir William Preece, it remained without a scientific name until called "induction" by Clerk-Maxwell.

Professor E. Sacher, in Vienna (December, 1877), found that signals from three cells sent through a wire 120 metres in length were clearly heard in a telephone on a parallel wire 20 metres distant.[1] Some twelve months later M. Henri Dufour, in Paris, confirmed these results with parallel wires 15 metres in length and separated by distances of up to 45 centimetres.

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[1] *Journal of the Telegraph* (New York), 1st and 16th October and 1st November, 1877.

These researches, coupled with the frequently demonstrated extreme sensitivity of the Bell telephone, caused several scientists to turn their attention more directly to the problem of wireless communication and with some anticipation of arriving at a practical solution. In this connection Professor Trowbridge, of Harvard, pointed out that the newly invented Bell telephone was so sensitive that, although it did not actually fulfil the conditions required by Steinheil for "some means that would stand in the same relation to electricity that the eye stands to light", it was certainly a very close approach thereto.

John Trowbridge, born at Boston, Mass., on 5th August, 1843, was the son of a physician. He studied at the Latin School, Boston, and at the age of 18 entered the Lawrence Scientific School and graduated in 1865. The following year he was appointed tutor in Physics at Harvard, where he remained until 1869, when he became Assistant Professor of Physics in the Massachusetts Institute of Technology. He returned to Harvard in the following year, first as Assistant Professor of Physics and later as full Professor, which position he occupied until his resignation in 1910—a continuous service of forty years. In 1873 he took his degree of Doctor of Science and in 1888 became Rumford Professor. He died on 18th February, 1923, in his 80th year.

Trowbridge's father, believing in the adage of Bacon that, if given the range of a library, a boy will select the food most suitable to his tastes, had provided his son liberally with books rather than with instructors. Being fond of art himself, he stimulated a certain fondness for drawing in the child. The consequence of this training was that, at the age of 14 or 15, John had acquired a considerable amount of information on a variety of subjects and a facility for drawing, but no systematic training in languages or in mathematics. While many of his schoolmates, who had been trained in schools from an early age, grew tired of intellectual effort, he came to the subjects of mathematics and the sciences with a certain freshness. His strong taste for art made his friends predict an artistic career as the only one suitable for him, but his graduation and the evidence of strong mathematical tastes determined his future career.

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[1] *Electrician*, vol. i, p. 194.

When Trowbridge went to Harvard in 1870 the subject of physics was taught merely by lectures and recitations. He immediately secured a small room and fitted it up as a physical laboratory, and from this small beginning arose the Jefferson Physical Laboratory, at one time the largest laboratory of its kind in America, of which he was Director for twenty-two years.

Trowbridge's first scientific paper dealt with a new form of galvanometer, the *Cosine Galvanometer*, before the invention of which the tangent and the sine galvanometers were the only forms of galvanometer known in scientific literature. The cosine galvanometer, which made use of the principle of a vertical coil movable about a horizontal axis, gave an additional adaptation, and afforded a convenient method of measuring strong electrical currents. Trowbridge's next paper was upon animal electricity, the result of long investigations having deepened the conviction that the observations of Du Bois-Reymond had not established the existence of so-called muscular electrical currents. Trowbridge believed that the operation of detaching a muscle from its position and examining its electrical condition by means of a galvanometer must result in experimental errors that previously had masked any electrical currents due to the generation of electricity in the muscle itself. He pointed out that although the torpedo and a few electrical fishes that are able to generate electricity are equipped with certain organs for the generation of electricity, this is not true of the ordinary muscle. In the latter case the effects observed are due to the contact of the electrodes with fresh muscular tissue—in other words, to the fact that the so-called muscular electrical currents had their seat in the contact between the electrodes and the fluids of the fresh muscle. These results, being in opposition to the belief of the leading German physiologists, were not approved at the time, although they were accepted subsequently.

IV

Trowbridge was one of the first to measure the relative efficiency of various forms of dynamo-electric machines, his experiments being conducted at the United States Torpedo Station at Newport, Rhode Island. For this purpose he invented a new form of electrical dynamometer, that enabled the strongest electrical current to be measured without subdividing it.

In the course of this investigation he was struck by the large amount of heat developed by the reversals of magnetism in the core of an electro-magnet. He undertook a separate investigation, together with the chemist of the Torpedo Station (Mr. Walter N. Hill), upon the amount of this heating, examining its effect in a great variety of steels of different composition, in the hope of arriving at a practical method of testing the composition of steel. The results of the investigation strengthened the general belief of that time that the heat due to the reversal of magnetism must be attributed to induced currents in the iron or steel, rather than to reversals of magnetism in molecular magnets.

Among the instruments invented by Trowbridge was a new form of induction coil, in which two primary coils were employed, and two induction coils, the poles of the electro-magnets being connected by thin plates of iron. The spark was produced from the combination by a mechanical break and had considerable heating effect.

Trowbridge's researches included the study of the conveyance of heat by an electrical current in various metals, particularly in nickel; the availability of a thermal junction for measuring very low temperatures; the formation of vortex-rings in liquids, and an interpretation of the mathematical formulæ relating to vortex-rings in water; the propagation of heat at right angles to, and in the direction of, the lines of magnetic force; the effect of displacement of the compass in the Helmholtz form of Gaugain galvanometer. He also wrote a paper on the cause of the disturbances heard on telephone lines.

V

Trowbridge's attention was probably drawn to the possibility of wireless communication by hearing of Bell's work in this connection, or, perhaps, with a desire to follow up the earlier work of Morse in the same subject. However that may be, he certainly was interested in the subject of induction some time prior to 1880. In that year he read a paper, *The Earth as a Conductor of Electricity*, before the American Academy of Arts and Sciences.

As we have already mentioned, A. G. Bell was (in 1876) interested in the phenomena of the audibility of time signals heard in several telephone circuits not connected with the original transmitting circuit. Trowbridge also investigated the phenomena in connection with time signals transmitted by the Observatory clock at Harvard College (Cambridge) to Boston, some four miles away. The ticking of the clock was audible in all the telephone circuits between Boston and Cambridge that ran near the Observatory line. This phenomenon had been attributed to induction, but Trowbridge expressed it as his opinion that this was not the cause. He formed his opinion on a mathematical analysis by which he showed that it is impossible to transfer telephonic messages by induction from one wire to another unless the two run parallel and close to one another for a considerable distance. His theory was that the ticking was heard in the other circuits through leakage from the clock circuit in the earth connection and imperfect insulation.

He proceeded to made a survey of the country around Cambridge in order to study the extent of the electrified ground areas around the Observatory clock circuit. He used a wire between 500 and 600 ft. in length, earthed at each end, and a telephone in circuit. The ticking could be plainly heard at a distance of 220 yards from the Observatory. At a mile distant the ticking was heard in a telephone connected to the gas pipes of a house at one end, and the water pipes of a second house at the other, some 50 ft. only separating the two buildings. Signals between Boston and Waltham (10 miles apart) were also heard when the terminals of the telephone were immersed in a lake at Cambridge, the lake being some four miles from the nearest point of the Boston–Waltham wires.

Trowbridge carried out innumerable other experiments on similar lines, resulting in the definite pronouncement that any point where electricity is discharged to earth is the centre of waves of electrical energy, which widen as do the ripples of a pond and decrease in strength according to the increase in distance from the point of origin. He also stated as a fact that if the earth be tapped at two points of different potential, telephonic evidence of their existence will be obtained. In connection with the latter fact he pointed out that the two points at which the earth is tapped need not be very distant, if near the source of the energy, but that the further the tapping telephone is from the source, the wider apart must the two tapping wires be placed.[1]

VI

The possibility of telegraphing across the Atlantic without wires had previously been discussed—as we have seen—and the subject was now revived by Trowbridge.

> "The theoretical possibility of telegraphing across the Atlantic without a cable", he wrote, "is evident from the experiments I have undertaken. The practical possibility is another question. Powerful dynamos could be placed at some point in Nova Scotia, having one end of their circuit grounded near them and the other end grounded in Florida, the connecting wire being of great conductivity and carefully insulated throughout. By exploring the coast of France, two points on surface lines not at the same potential could be found; and by means of a telephone of low resistance, Morse signals sent from Nova Scotia to Florida could be heard in France. Theoretically, this is possible; but practically, with the light of our present knowledge, the expenditure of energy by the dynamo electric machines would be enormous." [2]

Abandoning this imaginative project of signalling across the Atlantic, he suggested (in 1880) that his method might be used by ships at sea, for communicating with each other. Each ship was to be equipped with a powerful dynamo, one terminal of which was to be earthed in the sea at the bow of the vessel. The other terminal was to be connected to a long insulated wire, which was to be trailed over the stern and fastened to a buoy, not insulated. The current would thus be spread over a large area of water and could be picked up by other ships, equipped with similar trailing wires, the signals being received by means of a telephone connected in the circuit instead of a dynamo, as in the transmitting ship. Each ship would, of course, be equipped both with a dynamo and a telephone circuit, with a suitable "change-over" arrangement to enable, what Trowbridge quaintly calls, "reciprocal correspondence" to be maintained. By these means, he suggested, collisions at night or during fog would be prevented.[1] He thought that a dynamo that could supply one hundred incandescent lamps with current could establish a sufficient difference of potential between the water at the bow and at the end of a trailing wire half a mile in length to affect a telephone on an approaching ship while yet half a mile distant.

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[1] In this connection it may be remarked that Steinheil had already pointed out, in connection with his "earth battery", that "the spreading of the galvanic effect is proportional . . . to the square of the distance"—p. 172, in his paper *Telegraphic Communication, Especially by Means of Galvanism* (1873).

[2] Trowbridge overlooked the advantage of using large condensers between the dynamos and the earth connection.

For four years Trowbridge was engaged on these experiments and (in 1884) he announced a modification of the system, which he called aerial telegraphy. By this he hoped to enable ships also to communicate with each other by using wires stretched from the yard-arms, the ends of the wires dipping into the sea on each side of the ship. In this case a delicate galvanometer was, for some unknown reason, substituted for the telephone.

It may perhaps be claimed for Trowbridge that he was a pioneer of the modern wireless lighthouse, for he suggested that his aerial telegraph could be installed on dangerous rocks and warning signals sent out.

> "The method could also be applied to saturating the water around a rock," he wrote, "and you could take electrical soundings, so to speak, and ascertain your position from electrical maps carefully made out."

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[1] This idea is identical with A. G. Bell's suggestion of two years earlier, with which, as we have already seen, Trowbridge was fully acquainted.

VII

Continuing with his researches, Trowbridge suggested (21st February, 1891) that it was possible to signal without wires by means of electro-magnetic induction (Fig. 14). Although he was not the first to study the subject from this new aspect, it is chiefly to his systematic researches that subsequent workers in this particular field owe their inspiration. He proposed that ships should be equipped with ten or twelve wires, stretched from the yard-arms, and their ends connected either to a powerful battery or to a dynamo. Wires stretched similarly on the ship to receive the signals were to be connected to a telephone receiver, in order to detect the signals.

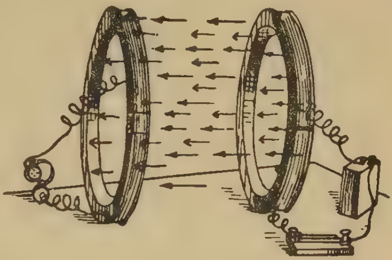

Fig. 14—Induction

If two coils of wire are placed close together and a current passed through one of them, a current will be induced in the other at those instants at which the first current is started or stopped.

Experiments were carried out on board ship, and it was noticed that signals were strongest when the two coils were parallel to each other. Trowbridge suggested that by this fact the direction of a signalling vessel could readily and accurately be found—an early suggestion of modern directional wireless !

Although in theory Trowbridge had in a manner practically solved the problem of wireless communication, in practice the difficulties of all his systems were too great to be overcome. In his induction method, for instance, to produce an audible note in the telephones of a ship at only half a mile distance would have required coils composed of ten turns of wire with a radius of 800 ft.

> " The hope ", he says, " that we shall be able to transmit messages through the air by electricity, without the use of connecting wires, is supposed by some to indicate its realization at a future day."

Altogether his results were unpromising, however, and only seemed to emphasize the difficulties of the subject. He himself seems to have been greatly disappointed, for in 1891 we find him expressing his opinion that :

> " It is hardly probable that any electrical method could be devised in which air or the ether of space could advantageously replace a metallic conductor on land for signalling over considerable distances. The curvature of the earth would probably demand a system of frequent repetition, which is entirely obviated by the use of a wire."

These are indeed remarkable opinions. Little did Trowbridge suppose that in less than five years' time a young Italian would be transmitting and receiving wireless signals through " the ether of space " for distances of two miles and upwards, before representatives of the British Navy and Army ! But, as we shall see shortly, events were to move rapidly in the next few years, for the work of the pioneers of wireless was beginning to bear fruit.

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CHAPTER IX

DOLBEAR NEARLY FORESTALLS MARCONI ; T. A. EDISON COMMUNICATES WITH TRAINS

LOOKING back over the work of the pioneers of wireless we are forcibly reminded of the fact that more than one worker had the secret of a successful system in his grasp but failed to realize it. One of these was A. E. Dolbear, Professor at Tufts College, Boston, U.S.A., who actually succeeded (in 1883) in transmitting signals through space without wires and came very near to forestalling Marconi. This remarkable man has been described, by one who knew him, as a " theoretical scientist, interested primarily rather in discovering new possibilities that lie in the great unexplored force around us, than in marketing them ".

Amos Emerson Dolbear (*b*, Plate IX) was born at Norwich, Conn., on 10th November, 1837, and died at Boston, Mass., in 1910. He graduated at the Ohio Wesleyan University in 1866 and was appointed Professor of Physics at Tufts College, Boston, in 1874. He was awarded a silver medal at Paris in 1881 and a gold medal at London in 1882 for his electrostatic telephone. He was a most active investigator in physics, and apart from his telephone inventions, to be mentioned shortly, he invented (in 1889) a spring-balance ammeter, and for some time was engaged on the difficult problem of the cubical organ pipe, in which there lies enormous power but which requires an almost unlimited source of wind supply. Some of his other contributions to science included the electric gyroscope, used to demonstrate the rotation of the earth ; tuning-forks, for the illustration of Lissajous curves ; the opeidoscope, for the demonstration of vocal vibrations ; and a new system of incandescent lighting. Almost every problem came under his notice, and those who subsequently ventured into physical or electrical fields found almost invariably that he had already written or spoken on almost every subject.

As a philosopher Dolbear was one who saw something deeper in biology and something more wonderful in physics, even than had been discovered in these sciences, both of which he had mastered. He was a champion of the etheric theory of atoms as the origin of all physical phenomena, and of the hypothesis known as the vortex in the ether, producing atoms as rings are produced from vapour. Mathematically the vortex theory of the construction of atoms is demonstrable, and the subsequent discoveries of the separation of the theoretic atom into ions infinitely less in volume simply removes the marvel into a more distant field—the essential conception remaining the same. In Dolbear's book, *Matter, Ether, and Motion*, it will be seen how close he came to the spiritualization of the physics of the universe. Matter to him was nothing less than spirit in action, for he had seized on the basic idea that spirit was at the foundation of all phenomena.

> "In whatever direction one pursues physical sciences," he wrote, "he is at last confronted with a physical phenomenon with a super-physical antecedent where all physical methods of investigation are impotent. Such considerations raise the theistic hypothesis to the rank of such physical theories as the nebular theory of the origin of the solar system and the undulatory theory of light."

II

As early as 1864 Dolbear had invented a writing telegraph. He discovered the convertibility of sound into electricity in 1873, and when the Bell telephone came into public notice he had already in use a speaking telephone of his own invention on which he held a patent that was afterwards purchased by the Western Union. It was his telephone, indeed, that was the subject of the litigation between that company and the Bell Telephone Company. His system, for which he received a bronze medal at the Philadelphia Exposition, was entirely different from Bell's, and it was claimed for it that it was capable of transmitting the human voice to a greater

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[1] In the Preface to his *Matter, Ether, and Motion.*

distance than any device in use at the time. In 1879 he invented his electrostatic telephone, with which (in 1881–2) satisfactory communication was carried on between Boston and New York and Boston and Wilkesbarre, Penn. In 1882 the Dolbear telephone was in effective operation between London and Manchester and London and Glasgow, and it has been claimed that no other telephone had been as successful over such distances as these. In 1884–6, in experiments in Russia, carried out for the Russian Government officials, telephonic communication was successfully maintained with it between St. Petersburg and Reval (150 miles), St. Petersburg and Bologna (200 miles), and St. Petersburg and Moscow (400 miles).

The system at the transmitting station consisted of the regular microphonic transmitter controlling a primary circuit of about one-half to three-quarters of an ohm and a secondary of from 2,500 to 3,000 ohms. There was about 1¼ lb. of No. 22 B. and S. gauge wire on the secondary. One end of the secondary was connected to earth at the transmitting station, the other being connected at the receiving station with the one plate of the Dolbear condenser telephone, the other plate being connected to earth. That articulate speech could be obtained from a condenser was, so far as records show, unknown to anyone prior to Dolbear's wonderful discovery.

The electrostatic telephone was not simply an imitation of what Professor Bell or others had done, but was an entirely new departure.[1] This is clear from the following report of the discussion that followed the reading of Professor Dolbear's paper on his telephone system before the American Association for the Advancement of Science, held at Minneapolis in August, 1883. Professor H. A. Rowland said:

> "Of course, this is on an entirely different principle from our telephone. . . . I don't want to say anything about patent laws or decisions on this subject, for they have nothing to do with this, but, scientifically, this is an entirely different instrument from the Bell instrument, and I am especially interested on that account."

If Professor Rowland, of Johns Hopkins University, could not speak with authority, no man could.

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[1] *Science* of 31st August, 1883, pp. 285–6.

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III

It was in 1882 that Dolbear brought out his system of wireless telegraphy, and on 24th March in that year he filed his application for a patent,[1] at the U.S. Patent Office, for a "Mode of Electric Communication". In the second paragraph of his specification he states:

> "My invention relates to establishing electric communication between two or more places without the use of a wire or other like conductor; and it consists in connecting the transmitting instrument with a ground, the potential of which is considerably above the normal, and the receiving instrument with a ground the potential of which is considerably below the normal, the result being that an impulse from the transmitter sufficient to cause the receiver to give intelligible signals is transmitted through the earth without the need of any circuit, such as has heretofore been deemed essential."

Towards the end he says:

> "I have spoken only of telephone instruments, as these give the best results; but any electric instruments may be used capable of utilizing the currents passing through the earth from [the two points], and the strength of such currents can be largely increased by increasing the positive potential of "o" [at the transmitting station] and the negative potential of "o" [at the receiving station]."

The specification concludes with the remark:

> "What I claim is—the art above described of communicating by electricity, consisting in first establishing a positive potential at one ground and a negative at another; secondly, varying the potential of one ground by means of transmitting apparatus, whereby the potential of the other ground is varied; and, lastly, operating receiving apparatus by the potential so varied, all substantially as described."

Dolbear came to London and, before the Society of Telegraph Engineers and Electricians, he read (23rd March, 1882) a paper on the telephone, at the conclusion of which he not only referred to his discovery of the practicability of wireless, but gave an actual demonstration of his system. This was probably the first occasion on which the human voice was transmitted by wireless. In his paper Dolbear reviewed the state of the telephone up to that time. He mentioned the work of Reis especially, also that of Professor Bell, of whom he said: "Professor Bell proposed—and he (the lecturer) believed that he was the first in the world to do so—to speak to the armature of a magnet with the expectation that some one else listening to the armature of another magnet in the circuit would be able to hear what was said."

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[1] U.S. Patents No. 350299 (granted 5th October, 1886) and No. 355149, both of which were subsequently acquired by the United Wireless-De Forest Co.

Dolbear then proceeded to explain his electrostatic system of telephony, in which a condenser was the receiving instrument. He exhibited the working of the instrument and called attention to the fact that he had set up twelve instruments in the room, all in connection with the same circuit, and he had a transmitter in that room and a second transmitter in another room. The length of wire was not great, but it was sufficient to show the action of his instrument. He wanted to show that it was a working instrument, and that the battery and everything was included in the box that he held. From another room an assistant counted ten, which was heard distinctly in all parts of the room, and the same result followed when "God save the King" and "Yankee Doodle" were whistled. The services of a cornet player were afterwards brought into requisition with equal success, the audience in the lecture-room hearing distinctly.

"Here is an instrument", said Dolbear, "that has but a single plate in it, not two, as in the previous one. If this is simply connected with the wire, there is no special difficulty in hearing what is said in the instrument." The chairman of the meeting, at the request of the lecturer, listened at the instrument, and the assistant in the other room counting ten, he stated: "The articulation is quite perfect, but not as loud as the other".

Dolbear pointed out that he had "gone one step farther. Here is my device, and I have found that it is not necessary to have it attached to the circuit at all. It has been disconnected". "The chairman again listened to the assistant counting and stated that he heard 'perfectly'."[1] Dolbear concluded his paper by saying:

> "I can hardly conceive how it is possible to make anything more simple. It consists of two plates in proximity to one another mounted in a convenient handle. I have heard it 50 ft. from the terminal. It

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[1] *Electrician*, 1st April, 1882.

is only necessary to bring wires anywhere in the neighbourhood, and as many as are present who are provided with receivers can hear all that is said." [1]

With the exception of Bell's photophone, which was based on a different principle, this was the first instance of the human voice being transmitted by wireless telephony. The demonstration was carried out in the presence of a large and exceedingly intelligent audience, for the Electrical Exhibition (a continuation of the Paris 1881 Exhibition) was in progress at the time and every scientist of note in Great Britain was present and also a number of others from Continental Europe. Although wireless telephony was here fully set forth and demonstrated in the heart of London, and before an authoritative and representative audience, the world had to wait another sixteen years for a Marconi to force an inferior article—wireless telegraphy—on public attention !

IV

Dolbear's apparatus consisted of a microphone, battery, and induction coil (Fig. 15). One end of the induction coil was earthed, the other end being connected to a condenser. Reception was made by a telephone receiver connected at one end to earth, at the other to a condenser connected in series with a battery to a second condenser for reasons which are not evident. Speaking into the microphone M caused pulses of potential to be induced in the secondary coil and therefore in the ground at A. In consequence earth currents flowed, producing similar pulses of potential at B, so that the speech was reproduced in the receiver. Instead of the microphone, Dolbear also used an interrupter and a Morse key in the primary—in other words, an ordinary spark induction coil, with a larger battery than could be used with a microphone, enabled greater ranges to be recorded.

Dolbear's system was a near approach to wave signalling, since the condensers might consist of elevated wires or plates, but, of course, it is evident that there was no attempt to generate and use high-frequency oscillations.

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[1] For full report of the lecture see also "On the Development of a New Telephone System" in the *Journal of the Society of Telegraph Engineers*, 23rd March, 1882, pp. 142–3.

In 1883 Dolbear further described his apparatus and experimented before the American Association for the Advancement of Science.

"My first results", he said, "were obtained with a large magneto-electric machine with one terminal grounded through a Morse key, the other terminal out in free air and only a foot or two in length. The receiver had one terminal grounded, the other held in the hand while the body was insulated, the distance between grounds being about 60 ft. Afterwards, much louder and better effects were obtained by using an induction coil having an automatic break and with a Morse key in the primary circuit, one terminal of the secondary grounded, the other in free air, or in a condenser of considerable capacity, the latter having an air discharge of fine points at its opposite terminal.

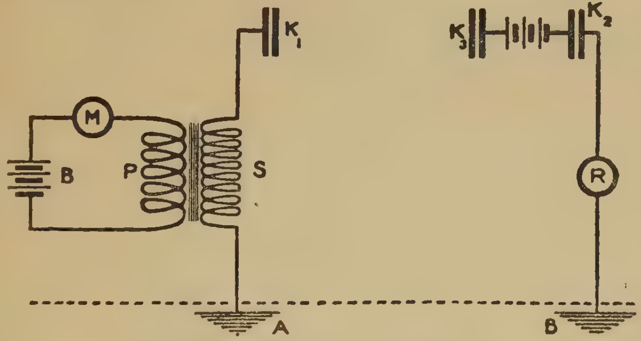

FIG. 15—DOLBEAR'S METHOD

M. Microphone.
K. Condenser.
B. Battery.
R. Receiver.
P. Induction coil.
S. Secondary coil.

"At times I have employed a gilt kite, carrying a fine wire from the secondary coil. The discharges then are apparently nearly as strong as if there was an ordinary circuit. The idea is to cause a series of electrical discharges into the earth at a given place, without discharging into the earth the other terminal of the battery or induction coil—a feat that I have been told so many, many times is impossible, but which certainly can be done. An induction coil isn't amenable to Ohm's law always!

"Suppose that at one place there be apparatus for discharging the *positive* pole of the induction coil into the ground, say 100 times per second, then the ground will be raised to a certain potential 100 times per second. At another point let a similar apparatus discharge the *negative* pole 100 times per second; then between these two places there will be a greater difference of potential than in other directions, and a series of earth-currents, 100 per second, will flow from one to the other. Any sensitive electrical device, a galvanometer or telephone, will be disturbed at the latter station by these currents, and any intermittence of them, as can be brought about by a Morse key in the first place, will be seen or heard in the second place. The stronger the discharges that can be thus produced, the stronger will the earth-currents be, of course, and an insulated tin roof is an excellent terminal for such a purpose. I have generally used my static telephone receiver in my experiments, though the magneto will answer.

" I am still at work upon this method of communication, to perfect it. I shall soon know better its limits on both land and water than I do now. It is adapted to telegraphing between vessels at sea.

" Some very interesting results were obtained when the static receiver with one terminal was employed. A person standing upon the ground at a distance from the discharging point could hear nothing; but very little, standing upon ordinary stones, as granite, blocks, or steps; but standing upon asphalt concrete, the sounds were loud enough to hear with the telephone at some distance from the ear." [1]

At first Dolbear could send signals only over distances of about half a mile, but later he claimed to have sent and received signals over thirteen miles. Had Hertz made his discovery of the waves that to-day bear his name, there seems little reason to doubt that Dolbear would have forestalled Marconi. His projection into free air of the ungrounded terminals of the transmitting and receiving apparatus is, in effect, very similar to the use of the vertical aerial of Marconi's early system. His condensers and kites " carrying fine wires " were yet another anticipation—had he employed thick wire he would have been more successful.

In 1884 Dolbear demonstrated his apparatus at the Electrical Exhibition at Philadelphia. One terminal of his induction coil was connected to earth, the other being fitted with points for " discharging into the air ". Interesting results were obtained, the signals being clearly heard in the telephone when transmitter and receiver were separated by 100 ft. " By grounding the one terminal of the induction coil to the gas or water pipes, leaving the other end free," he wrote, " telegraph signals can be heard in any part of a big building and its neighbourhood, *without any connection whatever*, provided the person be well insulated." [2]

Although Dolbear was not unnaturally under the impression

[1] *Scientific American* (Supplement), 11th December, 1886.

[2] Ibid.

that it was the air that assisted to bridge the gap between transmitter and receiver in some mysterious manner, we know now that he was undoubtedly using the Hertzian waves, the existence of which was not to become known until six years later.

V

As was the case with Faraday, Graham Bell, and many other pioneers of wireless, Dolbear had a charming personability. He was modest to a degree, and his unwillingness to claim anything for himself, which characterized his life (with the one exception of the legal action he took on the telephone invention), was well illustrated when he was invited to write an article on New England inventors of the nineteenth century. Every name ever known to scientists from the six New England States was found in the article with the exception of that of Amos E. Dolbear!

As an inventor, Dolbear resembled many others, before and after him, gifted with imagination and inventiveness—he failed to develop his conceptions to the point of rendering them capable of commercial application. The law wisely says that the inventor must describe his invention in such terms that one skilled in the art may reproduce it and make it of practical use, and this Professor Dolbear failed to do. As we have seen, he appreciated the fact early in the 'eighties that wireless telegraphy meant ether-wave telegraphy, and that both to send and to receive messages aerial antennæ would be required. Although he did take out a patent on aerial antennæ at that early date, he stopped at that. He did not know how to set up electrical oscillations, nor did he know how to detect the infinitely feeble oscillations set up in his receiving antennæ by the incident ether-waves. Before commercial wireless telegraphy could become possible many additional discoveries were necessary and an enormous amount of experimental work had yet to be accomplished. Dolbear saw wireless telegraphy just as he might have seen a ship through the fog—and he knew he saw it—but the individual ropes and spars, the planks and timbers, he did not see at that time, nor could he be expected to see how they were put together. Although he had one of the main requisites of a great inventor, breadth of vision and boldness of conception, he failed to realize the importance of detail.

His peculiar attitude to scientific complexities is illustrated by an incident related by one of his pupils, W. H. Hooper, who later became Assistant Professor of Physics at Tufts College. He tells us that in the winter of 1877–8 he was assisting Dolbear with some experiments in telephony. Some fault developed in the transmitter, and, opening the box that contained it, Dolbear poked about for some minutes and then remarked, with an exclamation of disgust, " I can't make head or tail of all this mess of stuff ; see what you can do with it ! " It took his pupil but a short time to find and remedy the trouble. Hooper tells us that to him " the complexities of the system seemed natural, a thing to be grappled with and mastered. The wonderful thing was that the energy of the air vibrations in articulate speech could be transformed into a highly complex system of electric waves, and that the energy of these waves, after travelling a hundred or a thousand miles, could then again be transformed into articulate speech in the receiver. That the telephone should talk seemed natural to Professor Dolbear, the unnatural being the complexity of the mechanical details ".[1]

VI

Between 1838 and 1885 several methods of electrical communication with moving trains were proposed by different workers, the idea having attracted attention from the earliest days of the electric telegraph. In this connection it seems curious to-day to find that the main issue—that of universal wireless communication—should have been ignored in favour of a specialized section with only limited scope, and moreover a section that even to-day is not fully developed.

There was the suggestion of Edward Davy, the rival of Cooke and Wheatstone, who in a lecture on *Electric Telegraphy*, delivered in London during the summer of 1838, said :

> " I have a few words to say upon another application of electricity —namely, the purposes it will answer upon a railway, for giving notices of trains, of accidents, and stoppages. The numerous accidents that

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[1] Address to Tufts College Club, Boston, 7th April, 1910.

have occurred on railways seem to call for some remedy of the kind; and when future improvements shall have augmented the speed of travelling to a velocity that cannot at present be deemed safe, then every aid that science can afford must be called in to promote this object. Now, there is a contrivance, secured by patent, by which, at every station along the railway line, it may be seen by mere inspection of a dial what is the exact situation of the engines running either towards or from the station, and at what speed they are travelling. Every time the engine passes a milestone, the pointer on the dial moves forward to the next figure, a sound or alarm accompanying each movement.

"Not only this, but if two engines are approaching each other by any casualty, on the same rails, then, at a distance of a mile or two, a timely notice can be given in each engine by a sound or alarm from which the engineer would be apprised to slacken the speed; or, if the engineer be asleep or intoxicated, the same action might turn off the steam, independently of his attention, and thus prevent an accident." [1]

In 1842 W. F. Cooke described a system for signalling to trains, which was tried out the following year in the Queen Street tunnel, Glasgow, and in 1844 between Norwich and Yarmouth on the Great Eastern Railway. Dujardin (1845), Brett and Little (1847), Edwin Clark (1854), Bonelli (1855), and many others, proposed systems of train signalling all based on ordinary telegraphic principles and requiring connecting wires.

A. C. Brown, of the Eastern Telegraph Company, claimed to have been the first to suggest (in 1881) communicating with moving trains by induction. In a letter to the *Electrician*, 21st March, 1885, he says:

"My object was chiefly to provide an efficient means of fog-signalling, enabling the signalman to communicate directly with the drivers or guards. I proposed to run a wire along the permanent way, parallel with the rails, and to wind a coil of wire round the engine or carriage to be communicated with, in such a way as to get as long a length of wire parallel to, and as near to, the line-wire as possible, so as to be well exposed to the inductive action thereof. I then proposed to place in the signal-boxes a battery, signalling key, and rapid make-and-break instrument, or buzzer, and to thereby signal to the train, using a telephone in circuit with the train-coil as a receiver. By using an ordinary carbon transmitter in the line-wire, I also found it quite practicable to speak verbally to the train, so as to be distinctly heard in the telephone.

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[1] See Fahie's *History of Electric Telegraphy*, 1884, p. 407. The most perfect block system of the present day does not do anything like this. Davy's plan was actually patented by Henry Pinkus! (Patent specification No. 8644, of 24th September, 1840.)

"This design was embodied in a paper which, in the year 1881, I laid before the managing director of the United Telephone Company, but want of time and opportunity prevented its being put into practice. It was experimentally tried at that time, using wire coils, properly proportioned in length, resistance, and distance apart to the conditions that would be obtained in practice. It has since been simplified and arranged to produce both visible and audible signals on the engine or car by induction from a No. 8 iron line-wire across a space of 6 inches, with a current of only one-quarter ampere, or such as can easily be produced by the ordinary Daniell batteries used in railway work."

VII

Perhaps the most successful system, and certainly the most practical from the point of view of actual results, was produced by T. A. Edison.

Thomas Alva Edison (*a*, Plate X) was born on 11th February, 1847, at Milan, Ohio, where he lived until seven years of age, the family then moving to Port Huron, Michigan. He was the son of humble parents; his father was Dutch and his mother Scotch. The boy received but little education; what little he did receive was from his mother, who had been a teacher. He was a great reader, however, and when 12 years years of age he became a newspaper boy on the Grand Trunk Railways running into Detroit. He obtained the exclusive right to sell newspapers on this line and printed and issued the *Grand Trunk Herald*, the first newspaper to be printed on board a train. He contrived to while away the time on long journeys by conducting chemical experiments in a baggage van, until one day he set the van on fire through a bottle of phosphorus jarring on the floor. As a consequence of this accident he found himself without a job, the irate guard stopping the train at the next station and putting Edison off, with his printing plant and chemicals.

A friendly station-master, the life of whose daughter Edison had saved, taught him the elements of electric telegraphy, and Edison soon erected a line between the station and the neighbouring town and conducted a regular service. At 27 years of age he invented his printing telegraph, which brought him in a sufficient reward to enable him to leave the service of the railway companies and devote himself to research. He invented a number of electrical devices, including duplex telegraphy and an automatic system by which it was possible to send and record 3,500 words per minute between New York and Philadelphia. This was followed by his quadruplex system, which it is estimated effected an economy of over four millions sterling in America alone in line construction !

Edison next turned his attention to Bell's newly invented telephone, excellent as a receiver, but unsatisfactory as a transmitter, for the same instrument was used for both purposes. Edison soon perfected the carbon transmitter and his improved instrument is identical in principle with that in general use to-day. Edison was then sent for by the Western Union, the President of which asked him how much he wanted for his patent.

> " I had made up my mind that it was certainly worth £5,000," says Edison, " . . . still, it had been an easy job and only required a few months, and I felt a little shaky and uncertain. So I asked him to make me an offer. He promptly said he would give me £20,000. ' All right,' I said, ' it is yours on one condition, and that you don't pay it all at once, but pay me at the rate of £1,200 a year for seventeen years—the life of the patent '."

And so it was arranged.

Experimenting with the telephone had shown Edison the peculiar properties possessed by a diaphragm to take up and reproduce sound vibrations. One day in 1877 he made a rough sketch of his idea for a phonograph, and in a few hours his head workman had produced the model that embodied the principle of the " talking machines " of to-day.

Amongst his vast number of inventions, Edison is best known as the inventor of the electric lamp. In 1878 he commenced work on an incandescent lamp to replace the powerful arc-lamps then in limited use, which were not only too bright for general service but also too expensive and too troublesome ever to become popular. His experiments to find the ideal substance for the filament of his lamp were almost endless. Every conceivable material was tried without success until he obtained an inspiration that ultimately led him to adopt the carbon filament, the most satisfactory material for which he determined to be bamboo.

VIII

Amongst the numerous other problems that engaged Edison's attention was that of communicating with moving trains, his early experience on the railways no doubt emphasizing to him the great value of such a system. In or about 1875 Edison had observed something that at that time could not be understood. This was the possibility of drawing sparks from insulated objects in the neighbourhood of an electrical discharge. He did not follow up his discovery, considering the time was not yet ripe for investigating the subject. He named the result he had obtained the " Etheric Force ". News of the observations reached England in due course and Silvanus Thompson took the matter up and gave a demonstration to the Physical Society of London in June, 1876. He endeavoured to prove that the sparks could be accounted for on known principles, but his work in this connection must have rendered Thompson susceptible to methods of detecting real electric waves, when they were discovered later.

Edison had also (in 1877) some experience with induction in connection with the remarkable effects upon neighbouring circuits during the progress of the experiments with his " Singing Telephone ", as already described.

Although Edison had thus early at least twice touched upon the fringe of wireless, he was busily occupied and does not appear to have gone further into the subject until nine or ten years later, when (in 1883) Willoughby Smith made a similar suggestion in a paper on " Voltaic-Electric Induction ", read before the Institution of Electrical Engineers, 8th November.

> " Telegraph engineers ", he said, " have done much towards accomplishing the successful working of our present railway system, but still there is much scope for improvements in the signalling arrangements. In foggy weather the system now adopted is comparatively useless, and recourse has to be had at such times to the dangerous and somewhat clumsy method of signalling by means of detonating charges placed upon the rails.
>
> " Now, it has occurred to me that volta-electric induction might be employed with advantage in various ways for signalling purposes. For example, one or more spirals could be fixed between the rails at

any convenient distance from the signalling station, so that, when necessary, intermittent currents could be sent through the spirals; and another spiral could be fixed beneath the engine, or guard's van, and connected to one or more telephones placed near those in charge of the train. Then, as the train passed over the fixed spiral, the sound given out by the transmitter would be loudly reproduced by the telephone, and indicate by its character the signal intended.

"One of my experiments in this direction will perhaps better illustrate my meaning. The large spiral was connected in circuit with twelve Leclanché cells and the two make-and-break transmitters before described. They were so connected that either transmitter could be switched into circuit when required, and this I considered the signalling station. The small spiral was so arranged that it passed in front of the large one at the distance of 8 inches and at a speed of 28 miles per hour. The terminals of the small spiral were connected to a telephone fixed in a distant room, the result being that the sound produced from either transmitter could be clearly heard and recognized every time the spirals passed each other. With a knowledge of this fact I think it will be readily understood how a cheap and efficient adjunct to the present system of railway signalling could be obtained. . . ."

IX

No doubt Edison had his attention directed to this lucid suggestion, for with the assistance of E. T. Gilliland, Phelps, and Willoughby Smith, he brought out (in 1885) a system that made use of the ordinary telegraph wires running alongside the railway. Morse keys, induction coils, and telephones were used, the system operating first at Staten Island, U.S.A., then, a few months later, on the Chicago, Milwaukee, and St. Paul railroad. The system had the additional advantage that the same wires could be used simultaneously for regular telegraphic traffic.

The invention was thus described by a reporter who visited Edison's laboratory to inspect the latest wonder:

"Overhead was a board 8 in. in width, suspended from the ceiling by ropes fastened to one of its edges. One side of it was covered with tin-foil and was facing toward a wall 20 ft. distant. 'That', said Mr. Edison, 'is my railroad signal; I make electricity jump 35 ft. and carry a message. This is something quite new; no induction has ever been known that extended over 3 or 4 or 5 ft. This invention uses what is called static electricity, and it makes every running train of cars a telegraph station, accessible to every other telegraph station on the road. Messages may be sent to and from conductors, and to and from passengers. It requires no extra wire, either under the cars or at the side of the cars, but uses the ordinary telegraph just as it is put up at the side of the track. This white board is a receiver and transmitter. A board like it is to be fastened lengthwise along the peak of each car, where it will be out of the way and will not be a blemish. When the train is telegraphed to, the message jumps from the wire on the side of the track and alights on this board, and is conveyed to the apparatus in the train below. It works beautifully from those wires strung yonder. I was as much astonished as anybody at finding out what could be done. It costs very little, moreover, as 300 miles of road can be equipped for £200 '."

This system was the forerunner of the modern "wired-wireless" and contained the germ of the idea adopted a few years ago in America, but of which nothing has recently been heard.[1]

Edison applied for a patent for his system in the U.S.A. on the 23rd May, 1885, but the patent was not finally granted until 29th December, 1891. His plan differed from Dolbear's in that a key is used to send out signals in place of the telephone used in the latter. His specification sets out all the uses to which a wireless telegraph may be adopted, such as transmitting signals from a shore to moving vessels, signalling across bodies of water instead of using submarine cables, and across land without the use of the telegraph lines. He provides for the supposed effect of the earth's curvature by interposing along the route condensing surfaces so arranged that there shall be always a clear air space between any surface and its immediate neighbouring ones in either direction.

The system was patented in England on 22nd June, 1885, in the joint names of Edison and Gilliland, and is fully described in their specification, No. 7583. It is pointed out that the object of the invention is to produce an apparatus for telegraphing between moving trains, or between trains and stations, by induction and without the use of connecting wires. Fig. 16 shows a station and two trains fitted with the apparatus for signalling. On the top or side of the carriage to be used as the signal office is a metallic condensing surface, which runs the entire length of the car. This consists of a strip of metal (A) about 12 in. in width, well insulated by blocks of glass. Alternatively, a thin sheet of metal or metallic foil, secured to canvas and similarly insulated from the body of the car, may be used. To increase the total condensing surface, all the carriages of the train are provided with these strips, connected by suitable couplings (*a*). A wire (B), connected with these condensing surfaces, extends through the apparatus to the carriage-truck so as to form an earth connection through the wheels and the rails.

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[1] It is perhaps of interest to note an early instance of "wired-wireless" in this country when on 3rd November, 1922, the Lord Mayor of Bristol spoke from Bristol to Marconi House, London, whence his voice was broadcast far and wide. He did this by "wired-wireless" over the ordinary trunk telephone lines between London and Bristol, the ordinary conversation being carried on along the same lines without mutual interference.

The apparatus consists of an induction coil (C), the secondary wire of which is of extremely high resistance, and is in the circuit of wire (B) in which is also connected a telephone (D) of high resistance. Although this is preferably an electromotorgraph telephone (the chalk cylinder of which is kept in constant rotation by a suitable motor, electrical or mechanical), a magneto-electric or other suitable form of telephone may be employed with equally satisfactory results.

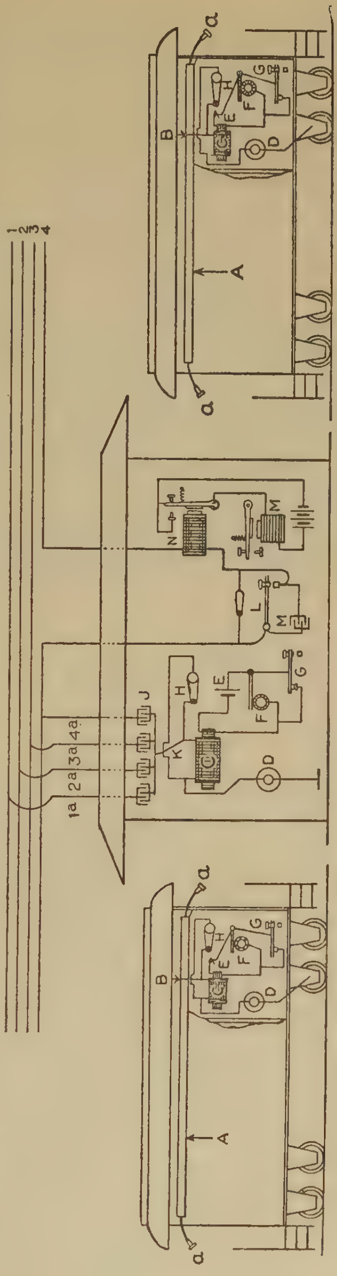

FIG. 16—EDISON AND GILLILAND'S SYSTEM OF WIRELESS TELEGRAPHY TO TRAINS

In the primary circuit of the induction coil (C) is a local battery (E) and a revolving circuit-breaker (F), or wheel having its surface broken by cross strips of insulation. Upon this wheel there rests a spring, the circuit being completed through the spring to the spindle of the wheel. This wheel is kept in rapid motion by a suitable motor, electrical or mechanical, the current vibrations produced by it being a great number per second and audible in the telephone receiver. The circuit-breaker is shunted by a back-point key (G) which normally short-circuits it and prevents it from affecting the induction coil. A switch (H) short-circuits the secondary wire of the induction coil when receiving, and is opened in transmitting.

The whole of the ordinary telegraph wires 1, 2, 3, and 4, grounded at their ends, and running on poles at the side of the track, are used to convey the signals. They form one surface of the condenser, the strips on the carriages forming the other, the intervening body of air being the dielectric.

Signals are transmitted by working the key (G) in the transmitting office on one train and so causing static impulses on the condensing surfaces upon the carriages. This affects the telegraph wires at the side of the track, and these in turn affect the condensing surface upon the carriages of the other train, so causing impulses audible in the telephone of the receiving carriage.

A large metallic condensing surface is erected at each signalling station between the telegraph wires. This may be attached to a frame supported from the telegraph poles or from separate poles. A wire runs from this condensing surface to the station, where it is connected to ground through the same character of transmitting and receiving apparatus as already described.

Instead of using this condensing surface outside the station, a separate wire 1*a*, 2*a*, 3*a*, or 4*a* may be attached to each telegraph wire and run into the station, where it is connected to one side of a condenser (J). The other sides of the several condensers (J) are connected together, and by a common wire (K) to earth through the transmitting and receiving apparatus.

The telegraph wires are kept constantly closed for transmitting the induction impulses by shunting the regular Morse

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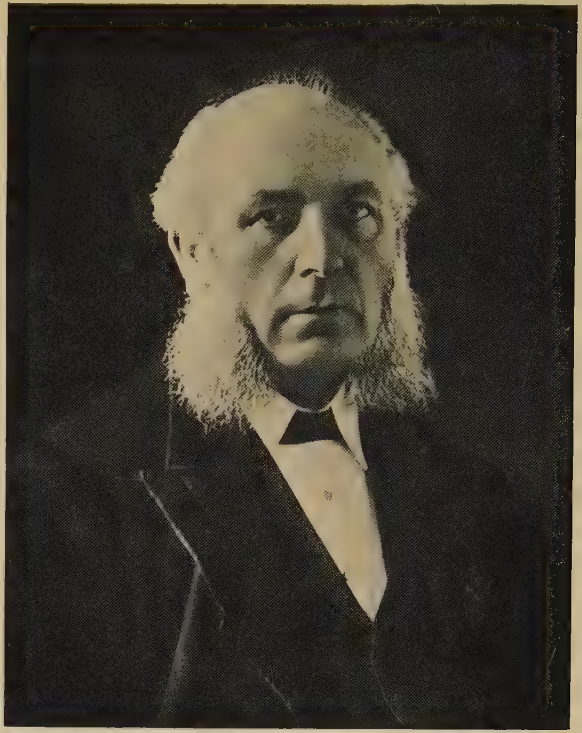
THOMAS ALVA EDISON
(b. 1847)



WILLOUGHBY SMITH
(1828-1891)

keys (L) by condensers (M). These condensers do not interfere with the ordinary telegraph work over such wires, for they form constantly closed paths for the induction impulses and are independent of the working of the ordinary Morse keys.

The signalling is conducted by Morse characters, or by numerical signals in accordance with an established code, and the ordinary Morse relay and sounder are shown in the diagram at (N) and (O) respectively. As the stations are connected for railway signalling inductively with the line-wires exactly as are the trains, signals are received and transmitted by a station in a similar manner.

Speaking of the possibilities of his system, Edison, early in 1886, said:

> "The outcome is easy to predict. Special correspondents may, in the future, wire their dispatches straight to the offices of their journals. Railway business will be expedited to a degree undreamt of as things are, and the risk of accidents will be largely diminished by knowing the position of trains and the cause of delay or accident, if any, at every stage of their route. Ships at sea, many miles apart, will be able to communicate by means of balloon-kites, soaring several hundred feet above their decks. Messages can be passed from ship to ship, and a casualty like that of the *Oregon* telegraphed to the nearest land. In times of war the applications of the air-telegraph system are obvious. Regions now remote from telegraphs could be brought within the civilized circle by means of mountain or forest stations equipped with the new apparatus. Even the man of business of the future may communicate with his employé as he journeys to and from his office, and save time or make money while he is literally on the wing. Not the least interesting feature of this new departure in telegraphy is the thought that, in its turn, it may be the harbinger of still more wondrous modifications of the system that has girdled the earth in a space inconceivably short when compared with that imagined by the fairy romancer who created Puck."[1]

In October, 1887, Edison's system was installed on the Lehigh Valley Railroad, where it worked very successfully. The following account of it was given in the press at the time:

> "The success of what is called 'railway train telegraphy' is now assured, and 6th October, 1887, will be a red-letter day in the history of the electric telegraph. On that day a special train left Jersey City with about 230 members of the Electric Club and guests of the Consolidated Railway Telegraph Company, in order to witness the working

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[1] *Weekly Irish Times*, 10th April, 1886.

of the system on the Lehigh Valley Railroad. The system is a combination of the best features of the inventions of Edison, Gilliland, Phelps, and Smith, and although the speed often reached the rate of about 60 miles an hour, messages were sent from, and received on, the train without difficulty, although the current or the 'induction' had to jump from the train to the line-wires, a distance of 25 ft. About four hundred messages were sent as the train ran from Perth Junction to Easton, amongst them a rather long one from Colonel Gouraud to Mr. John Pender in London." [1]

Some of the possibilities of the system are evidenced by the following report:

"One of the most interesting triumphs of invention has been achieved on the Lehigh Valley Railroad during the snowstorms of the past winter in the United States. This railway for some months has been using on its trains the system of communication known as train telegraphy. The wire, being of steel, and stretched upon stout poles only 15 or 16 ft. in height, withstood the fury of the storm. The Valley Railroad kept up constant communication with the terminus of the road, could define exactly their position, and, in short, had all the advantages of perfect telegraphic communication." [2]

Strange though it may seem, Edison's system, though working as well as could be wished, was a commercial failure. No one seemed to want to send or receive messages on a moving train, after the novelty of so doing had worn off, and ultimately the system fell with disuse, and the first wireless installation was taken out of commission. That Edison was convinced of its practical value is clear, however, because he subsequently took out another patent. This covered the application of his method of "aerial telegraphy" to ships, for communicating with one another at sea or to land stations. He also proposed the use of balloons covered with conducting foil and connected through transmitting or receiving apparatus to earth.[3]

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[1] *Public Opinion*, 4th November, 1887.
[2] Ibid., 13th April, 1888.
[3] U.S. Patent No. 465971. This patent was acquired by the Marconi Company in 1903.

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CHAPTER X

THE EXPERIMENTS OF MELHUISH, STEVENSON, AND WILLOUGHBY SMITH

THE results obtained by Trowbridge and Dolbear in America did much to inspire further research in England. W. P. Johnston (on 9th September, 1879) successfully transmitted across a canal 200 yards in width on a modification of Morse's system. He also at intervals experimented across the Hooghly, at Barrackpore near Calcutta, continuing the work of his predecessors, who had made similar trials (Schwendler, in 1876, and before him, Blissett, in 1858) with fair success. The experiments were continued by Johnston at various times during 1888, and as a result he was led to the following conclusions :

1. That up to a mile and a half it is perfectly easy to signal through a bare wire under water.
2. That for greater distances, judging from experiments, practical signalling is not possible.

In April, 1889, Johnston died, and W. F. Melhuish was appointed to his post of Electrician to the Indian Telegraph Department. He commenced an inquiry, and produced some very interesting results, which are embodied in a paper read before the Institution of Electrical Engineers on 10th April, 1890 :

"Having studied", he said, "the recorded labours of my predecessor, and learnt that by pursuing the same lines it was hopeless to expect to be able to signal through a bare wire across a river that had a greater breadth than one and a half miles, I resolved to change the class of signalling apparatus and to continue the experiment. Discarding continuous steady currents and polarized receiving relays, I adopted Cardew's vibrating sounder, and the sequel will show how completely successful the change of instruments proved to be. I began from the beginning, and tried to signal across a water-way without a metallic conductor by laying down two earth-plates on each of its opposite banks. Readable signals having been exchanged, the distance separating each pair of plates was varied, with the view of ascertaining how close the plates might be brought together, the signals remaining still readable. Readable signals were exchanged when the distance separating the plates was equal to the breadth of the river, reading becoming more difficult as the plates were made to approach each other, and clearer and more distinct as the distance between the plates was made to exceed the breadth of the river. I learnt from these experiments that in order to obtain signals of sufficient distinctness for the practical purpose of transmitting messages, it would be necessary to construct a line on each bank of a river much longer than the breadth of the river; and as the rivers along the coasts in India are extremely wide, I became impressed with the impracticable character of such an undertaking, and decided to strike out a new line.

" This new line was the laying of two bare uninsulated iron wires across the water-way parallel to each other and separated by a certain distance, the ends on each bank being looped together by means of an insulated conductor. Hence, though much of the circuit was laid under water, it was nevertheless a continuous metallic circuit. Beginning first with a complete square, by laying the wires as many yards apart as the river was wide, signals were instantly exchanged that were incomparably louder than those that were exchanged when the same area was bounded by four earth-plates. The length of each of the two wires under water was next gradually increased to 740 yards and the distance separating them gradually diminished to 35 yards, the strength of the signals diminishing proportionately, and ceasing to be readable when the wires were further approached. The conclusion arrived at from these experiments was that, for the practical and useful purpose of signalling messages across a broad river, in the absence of an insulated cable, a complete metallic circuit was at least desirable. Acting on this conclusion, it was sought to apply it practically, and the following experiment was carried out.

" At a distance of 15 miles west of Calcutta a cable is laid across the River Hooghly, which at this point is 900 yards in width. The iron guards of this cable were employed to form one of the metallic conductors, and at a distance of 450 yards down-stream a single wire, weighing 900 lb. per mile, was laid across the river to form the second metallic conductor, insulated land-lines having been run up to loop the two parallel conductors together. The experiment was quite a success, the signals being readable without difficulty.

" An experiment was next made on a defective cable across Channel Creek, at the mouth of the River Hooghly. This creek is crossed by two cables laid in the same trench; the length of each is 3,000 yards, and one of them had been completely parted by a steamer's anchor. Several attempts were made to signal across by using the guards of one of the cables as a lead, and the guards of the other as a return wire, but the efforts proved unsuccessful owing to the too close proximity of the cables. For every crossing there is a certain minimum distance apart at which the cables must be laid, and if this minimum, which depends on the breadth of the river, be exceeded, an absolute short-circuit becomes established. But although it was not possible here to signal through the iron guards, the most perfect signals were passed through the two conductors when they were formed into a loop, notwithstanding the fact that the two ends of the broken conductor were exposed in the sea and were lying at a considerable distance apart. An experiment was now made in order to ascertain what chance there might be in the future of signalling across the two conductors, should an accident occur to the good cable. Accordingly, the conductor of the good cable was disconnected in the cable-house from the signalling apparatus and placed upon the ground, when the signals, though greatly diminished in volume, still continued to be distinctly readable. It may, therefore, be reasonably inferred that should the good cable suffer a similar fate to that of the defective cable, communication can, by means of Cardew's sounders, be kept up by looping the ruptured conductors until arrangements can be made for laying a new cable or repairing the defective ones.

"It will probably suffice if, from the succeeding experiments that were made to test the efficiency of the vibrating sounder in the case of conductors breaking down at river crossings, I select the following three. They exhibit progressive evidence of the value of this signalling instrument, and culminate in establishing it beyond dispute as one that can be relied on for carrying on independent communication through the iron guards of cables while the insulated copper conductors form parts of other circuits.

"*Experiment No. 1.*—The Local line from the Central Office, Calcutta, to Garden Reach is about 4 miles in length, and at about midway the wire spans a small river. Vibrating sounders having been put in circuit at each end of this line, the wire where it crosses the river was taken down and laid along the bed of the water-way. Signals were loud and clear at both ends.

"From the success of this experiment it may be inferred that on any ordinary line, should the wire from accidental causes come off the insulator and make earth by touching the bracket, standard, or ground, or should the wire break and both ends of it be lying on the ground or in a watercourse, communication could still be maintained by means of the vibrating sounders.

"*Experiment No. 2.*—The line-wire that connects the town of Chandernagore with Barrackpore is about 10½ miles in length, 900 yards of which consist of a cable laid across the River Hooghly. Vibrating sounders having been joined up in the telegraph offices at Barrackpore and Chandernagore, the insulated conductor of the cable was thrown out of circuit, and the line-wire on each side of the river was joined to the iron guards of the cable. Thus for a length of half a mile out of 10½ miles the conductor was wholly under water, yet it was found quite feasible to transmit messages between the two offices.

" From the success of this experiment it may be reasonably inferred that in the case of certain cable crossings, where the rivers are not too wide, should the copper conductor of the cable make dead earth, or become insulated by parting, communication could still be kept up between the two offices on either side.

" *Experiment No. 3.*—The terminus of the Northern Bengal State Railway at Sara is separated from that of the Eastern Bengal State Railway at Damukdia by the River Ganges. The opposite banks of the river in this locality are connected by two independent cable crossings. The length of one of these crossings is 1 mile 610 yards, and of the other 4 miles. The distance which separates the two cable-houses on the Damukdia side is 3 miles 1,584 yards, and on the Sara side the cable-houses are only 1 mile 211 yards apart, giving a mean lateral distance in alignment of 2 miles 880 yards. The two cable-houses on each bank have an insulated connecting land-line.

" The connecting land-lines having been joined to the iron guards of the cables, two vibrating sounders were placed in circuit, one on each side of the river, when signals so strong were transmitted across that it was not difficult to read them at a distance of 6 ft. away from the receiving telephone.

" From the marked success of this experiment it may be inferred that at all river cable crossings where the cables are laid in separate alignments (and the farther apart the better), should the cables become interrupted, communication may still be maintained from bank to bank by using vibrating sounders, thus avoiding the delay, inconvenience, and cost of a boat service.

" It should also be remembered in the case of such a parallel cable crossing that, besides the circuits afforded by the copper conductors when these are in working order, there is always an additional local circuit available by means of the iron guards between the opposite cable-houses, and that this circuit could be used by means of the vibrating sounder as a talking circuit, in cases of necessity, without interrupting through working on either of the cables.

" It is desirable in circumstances similar to these to reduce all the resistance external to the actual connecting lines to as small a quantity as possible, and therefore, when messages are being transmitted, the telephone at the sending end should be removed from the circuit, as also should the vibrator from the receiving end. To effect this twofold purpose a special form of signalling key is requisite, and should be used."

II

In 1892, C. A. Stevenson suggested[1] that wireless telegraphic communication could be established between ships by coils of wire. Two years later he referred to his earlier suggestion, in a paper read before the Royal Society of Edinburgh (19th March, 1894), and mentioned that experiments on a large scale had been made, with the object of employing the method for communication between Muckle Flugga in the Shetlands and the mainland, distant some 800 yards. He calculated that the coils must be 200 yards in diameter and that there must be nine turns of Post Office wire and a current of 1 ampere to ensure success.

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[1] In *The Engineer*, 24th March, 1892.

"It is difficult", said Stevenson, "to understand how this system of coils, in opposition to the parallel-wire system, has not been recognized as the best; for assume that, with the arrangement we had, we heard equally with 100 cells by both systems, both having the same base (200 yards), then, by simply doubling the number of turns of wire on the primary and using thick wire, the effect would have been practically doubled, whereas by the parallel-wire system there is nothing for it but to increase the battery power. The difficulty of the current is thus removed by using a number of turns of wire. It must always be borne in mind that the effect is the result of simply increasing the diameter, keeping the current and resistance the same. The larger the diameter the better. What is wanted is to get induction at a great distance from a certain given base with a small battery power, and the laboratory experiments and the trials in the field show that the way to overcome the difficulty of the current is by using a number of turns of wire. The secret of success is to apportion the resistance of primary and secondary, and the number of turns on each, to a practical battery power."

In concluding his paper, Stevenson said:

"It has been attempted to be shown that the coil system is not only theoretically but practically the best; and I trust that we will soon hear of the Admiralty, etc., experimenting with it and ultimately putting it in practice. Meantime, my brother has recommended the Commissioners of Northern Lighthouses to erect the coil system at Muckle Flugga, and the Commissioners have approved;[1] and I hope soon to hear of the erection of this novel system of communication at the most northern point of the British Isles, as well as on our warships to assist in their manœuvring, by the establishment of instantaneous communication unaffected by wind or weather.

"The application of the coil system to communication with light vessels is obvious—viz. to moor the vessel in the ordinary way, and lay out from the shore a cable, and circle the area over which the lightship moorings will permit her to travel by a coil of the cable of the required diameter, which will be twice the length of her chain cable. On board the vessel there will be another coil of a number of turns of thick wire. Ten cells on the lightship and ten on the shore will be sufficient for the installation."

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[1] The installation of the system at Muckle Flugga did not materialize, because of financial difficulties.

III

Early in 1892 the Trinity Brethren placed the Needles Lighthouse at the disposal of the Telegraph Construction and Maintenance Company, in order that they might have an opportunity of testing a method of wireless communication, invented by Willoughby Smith, whose researches in the subject date back to 1883.

Willoughby Smith (*b*, Plate X) was born at Great Yarmouth on 16th April, 1828, and died at Eastbourne on 17th July, 1891, being buried at Highgate Cemetery. At 20 years of age he commenced his lifelong interest in telegraphic signalling and cable-laying. He first joined (in 1848) the Gutta Percha Company, London, and soon after commenced experimenting in insulating iron and copper wires with gutta-percha for telegraphic purposes. In 1849 his company undertook to supply 30 miles of insulated wire to be laid from Dover to Calais, and during the following year Smith superintended the manufacture and laying of this cable. He was subsequently engaged almost continuously in cable work and assisted Sir Charles Wheatstone with his experiments. In 1854 he laid the first Mediterranean cable, between Spezzia and Corsica, Corsica and Sardinia, and later between Sardinia and Cona in Algeria. On his return he was appointed Manager of the Gutta Percha works, which in 1864 were formed into the Telegraph Construction and Maintenance Company. In 1865 he was on board the *Great Eastern* and assisted in laying the cable from Ireland to Newfoundland, and again the following year when the second cable was successfully laid.

His first contribution to wireless appears to have been made in 1883, when he read a paper before the Institution of Electrical Engineers on wireless communication with trains.[1] In his system, which was something similar to that subsequently adopted by Edison, he suggested fixing one or more coils of wire between the rails at any convenient distance from the signalling station and sending intermittent currents through them. Another coil was to be fixed underneath the engine or under the guard's van and telephones connected in the circuit. Then as the train passed over the fixed spirals a signal would be picked up and loudly reproduced in the telephones. Phelps took the matter a step farther and, as we have already seen, in 1885 Edison and Gilliland developed it into a practical system.

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[1] As we have seen, it was one of his assistants who was the first to discover the peculiar properties of selenium, in or before 1878.

The result of these suggestions for communicating with trains seems to have shown Willoughby Smith that communication by induction was not practicable, and he appears to have then turned his attention to the alternative method of conduction by earth and water. In the *Electrician* (2nd November, 1888) he explained a method by which he had been able to signal to lighthouses and ships within a certain distance of the shore. From his shore station he laid two insulated copper wires 115 fathoms in length.

> " The ends of the wires, scraped clean, were twisted round anchors, their position being marked by buoys about 100 fathoms apart, and in about 6 fathoms of water. Midway between the two a boat was anchored with a copper plate hanging fore and aft about 10 fathoms apart, and consequently about 45 fathoms from either end of the anchored shore wires. This boat represented the sea station, and, owing to the state of the sea, a very wet and lively one it proved. Therefore, taking this fact into consideration, together with the crude nature of the experiment, it was remarkable with what distinctness and ease messages were passed. The last message sent from shore was, ' Thanks ; that will do ; pick up anchors and return '. To this the reply came from the boat, ' Understand ', and they then proceeded to carry out instructions. The boat employed was a wooden one, but it would have been much better for my purpose had it been of metal, for then I should have used it instead of one of the collecting plates, as the larger the surface of these plates the better the results obtained."

With this system signals were transmitted with " distinctiveness and ease ", and accordingly a patent (No. 8159) was taken out on 7th June, 1887.

The specification included the following particulars :

> " At the present time wherever electric telegraph communication is established between the shore and a lighthouse, either floating or on a rock, at a distance from the shore, it is effected through an insulated conductor or cable. Much difficulty is, however, experienced

owing to the rapid wearing of the cable, so that it is liable to break whenever a storm comes on, and when, consequently, it is most required to be in working order. By this invention communication can be effected between the sending station and the distant point without the necessity of metallic connection between them. In Fig. 17, A is a two-conductor cable led from a signal-station B on shore towards the rock C. At a distance from the rock one of the conductors is led to a metallic plate D similarly submerged on one side of the rock, and at such a distance from it as to be in water deep enough for it not to be affected by waves. The other conductor is led to another metallic plate E similarly submerged at a distance from the opposite side of the rock. F F are two submerged metallic plates, each opposite to the plates D and E respectively. G G are insulated conductors leading from the plates F F to a telephone of low resistance in the lighthouse H.

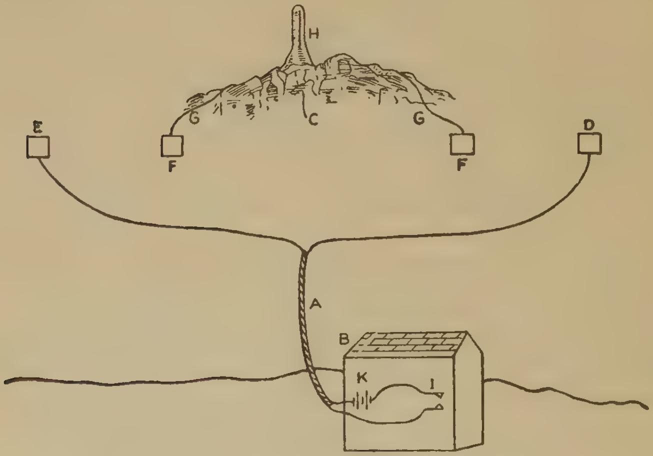

FIG. 17—WILLOUGHBY SMITH'S METHOD

" To communicate from the shore, an interrupter or reverser I and battery K are connected to the shore ends of the two-wire cable. The telephone in the lighthouse circuit then responds to the rapid makes and breaks or reversals of the current, so that signalling can readily be carried on by the Morse alphabet."

The system was tried in May, 1892, between Alum Bay, in the Isle of Wight, and the Needles Lighthouse, and communication established first with the telephone as a receiver and later with a vibrator and Morse key. A mirror speaking-galvanometer was found more satisfactory, however, and a call apparatus was devised and installed successfully. The current from two or three Leclanché cells was found ample to maintain communication through the gap of water 60 yards in length.

IV

On the recommendation of the Royal Commission, Willoughby Smith's method was subsequently installed at the Fastnet Rock, off the south-west coast of Ireland. The Fastnet Rock, 80 ft. in height and 360 ft. in length, with a maximum width of 150 ft., is one of the most inaccessible beacons on our coasts. It is so situated that it had been found impossible to maintain a cable, which was repeatedly broken by the waves, but Willoughby Smith's system placed it in electrical communication with the town of Crookhaven, 8 miles distant.

The shore end of the main cable was landed at a small bay called Galley Cove, about one mile to the west of the Crookhaven post-office, to which it was connected by means of a subterranean cable.

The "call" apparatus, which at the time of its installation was described as being both "novel and substantial", is interesting. It automatically adapted itself "to any variation in the earth or polarization current", and consisted essentially of two coils moving in a magnetic field. These coils were mounted one at each end of a balanced arm suspended at its centre and free to rotate horizontally within fixed limits. The normal position of the arm was midway between two fixed limiting stops. Any current circulating in the coils caused the whole suspended system to rotate until the arm was brought into contact with one or other of the stops—the direction of rotation depending upon the direction of the current. A local circuit was thus closed, which released a clockwork train connected to a torsion head carrying the suspending wire, and thus a counter-balancing twist or torsion was put into the wire, and this torsion slowly increased until the arm left the stop and again assumed its free position. If, however, the current was reversed within a period of, say, five or ten seconds, then the clockwork closed a second circuit and the electric bell was operated. By this arrangement, whilst the relay automatically adjusted itself for all variations of current, the call-bell would only respond to reversals of small period and not to the more sluggish movements of earth-currents. It is evident that one or more bells could be placed in any part of the building. The receiving galvanometer and the "call" relay worked very satisfactorily, it being stated that "any man of average intelligence can readily be taught in two or three weeks to work the whole system".

CHAPTER XI

PREECE INTRODUCES THE FIRST COMMERCIAL SYSTEM

THE first practical wireless system, that is to say one actually used for commercial purposes, was that evolved by Sir W. H. Preece, F.R.S., LL.D., at one time Engineer-in-Chief of the General Post Office.

William Henry Preece (*a*, Plate XI) was born at Carnarvon on 15th February, 1834, and was educated at King's College, London. In 1852 he entered the office of Edwin Clark, M.Inst.C.E., intending to become a civil engineer. In 1853, however, he joined the Electric and International Telegraph Company, and three years later was appointed superintendent of the Company's southern district. In 1860 he joined the London and South-Western Railway in connection with their telegraphic work, and was also Engineer to the Channel Islands Telegraph Company. In 1870 he transferred to the General Post Office as Divisional Engineer, and in 1877 was appointed Chief Electrician and in 1892 Engineer-in-Chief. After his retirement, in 1899, he continued to act as the G.P.O. Consulting Engineer until 1904. He died at Penrhos, Carnarvon, 6th November, 1913.

We have already learned that (in 1854) Preece was deputed to examine J. B. Lindsay's system of wireless communication. No doubt this early acquaintance with the subject had directed his attention to the problem, more particularly so, perhaps, when he entered the service of the Post Office. Between 1882 and 1898 he contributed several papers on the subjects of induction and signalling without wires to the British Association, Society of Arts, and other scientific bodies.

In his first paper, *Recent Progress in Telephony*,[1] he said :

"The discovery of the telephone has made us acquainted with many strange phenomena. It has enabled us, amongst other things, to establish beyond a doubt the fact that electric currents actually traverse the earth's crust. The theory that the earth acts as a great reservoir for electricity may be placed in the physicist's waste-basket. . . . Telephones have been fixed upon a wire passing from the ground-floor to the top of a large building (the gas pipes being used in place of a return wire), and Morse signals, sent from a telegraph office 250 yards distant, have been distinctly read. There are several cases on record of telephone circuits miles away from any telegraph wires, but in a line with the earth terminals, picking up telegraphic signals; and when an electric-light system uses the earth, it is stoppage to all telephonic communication in its neighbourhood. Thus, communication on the Manchester telephones was not long ago broken down from this cause; while in London the effect was at one time so strong as not only to destroy all correspondence, but to ring the telephone call-bells. A telephone system, using the earth in place of return wires, acts, in fact, as a shunt to the earth, picking up the currents that are passing in proportion to the relative resistances of the earth and the wire."

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[1] British Association Report, 1882.

II

In March, 1882, the cable across the Solent broke down from some unknown cause, and it became of great importance to know if communication across could be established by any other means. Preece "thought it a timely opportunity to test the ideas that had been promulgated by Professor Trowbridge".

The arrangements he suggested were similar to those used by Morse (in 1842) and Lindsay (in 1854), with both of which systems we know Preece was already familiar. Over these two pioneers of conductive transmission, however, Preece had the considerable advantage of the then recently invented telephone for receiving, and he used a rapidly vibrating reed, or "buzzer", to transmit the signals.

A plate of copper, about 6 ft. square, was immersed in the sea at the end of Ryde Pier. From thence an overhead wire passed to Newport and to the sea at Sconce Point, ending in a second copper plate. On the opposite shore at Hurst Castle was another copper plate, connected by a wire running through Southampton to Portsmouth and terminating in a fourth plate at Southsea Pier. Thus a complete circuit was formed, if the water is included, starting from Southampton to Southsea Pier (28 miles), across the Solent to Ryde

(6 miles), and on through Newport to Sconce Point (20 miles), across the Solent again to Hurst Castle (1¼ miles) and back to Southampton (24 miles) (Fig. 18).

Loud-speaking Gower-Bell telephones were first tried in the circuit, but conversation was found to be impossible. With a Theiler's sounder, or buzzer, a Morse key, and thirty Leclanché cells at Southampton, however, it was quite possible to hear the Morse signals in a telephone at Newport and vice versa.

Although the cable was repaired on the day following these experiments and further tests were thus rendered unnecessary, Preece's interest in the subject did not abate, and he neglected no opportunity of adding to his knowledge in wireless telegraphy.

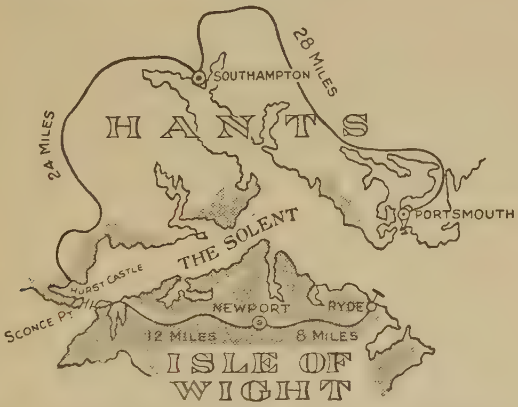

Fig. 18—Preece's experiment across the Solent

III

In the course of his duties at the Post Office, Preece had noticed many cases of the telephone picking up telegraphic signals from distant circuits. Of this there was no more remarkable instance than that of the famous Gray's Inn Road case, which occurred in 1884. Here it was discovered that telegraphic signals could be heard in telephone circuits that ran parallel to the underground cables. This was found to be possible even though the telephone wires were carried on poles over the roofs of houses some 80 ft. above the telegraph cables, which were buried in iron tubes at some depth beneath the roadway.[1] There were many other similar cases about the same time, one particularly interesting being that of the City and South London Electric Railway, the currents of which deflected the delicate galvanometers at the Greenwich Observatory, 4½ miles distant.

During the following year (1885) Preece arranged numerous experiments (which were carried out by A. W. Heaviside) with a view to testing the properties of induction in telephone wires and to determining to what distance parallel wires could be removed from each other before the inductive influence ceased to operate.

Two separate squares (the sides of which were 440 yards in length) of insulated wire were laid on the Town Moor at Newcastle, parallel to each other and a quarter of a mile apart. A conversation was easily carried on between the two circuits, and even when the squares were separated by 1,000 yards, inductive effects were still appreciable. It was found, however, that when the distance between the parallel wires exceeded the length of the wires themselves, the strength of the induced current in the second wire was considerably diminished. Several similar trials were held (in 1886) in different parts of the country. Between Durham and Darlington, the ordinary working currents in one line were clearly heard in a telephone on another line, running parallel but 10¼ miles distant! Similar inductive effects were obtained on the east and west coasts between Newcastle and Gretna on parallel lines even 40 miles apart.[2]

One of the most interesting of these experiments took place (also in 1886) on the Severn, between Gloucester and Bristol. Here there were no intermediate lines that could exercise a disturbing influence for a length of 14 miles and an average distance apart of 4½ miles. The experiments, although conclusive, showed that the range of audibility of the apparatus employed had been exceeded. It is interesting to note that in these tests it was unexpectedly found that the results

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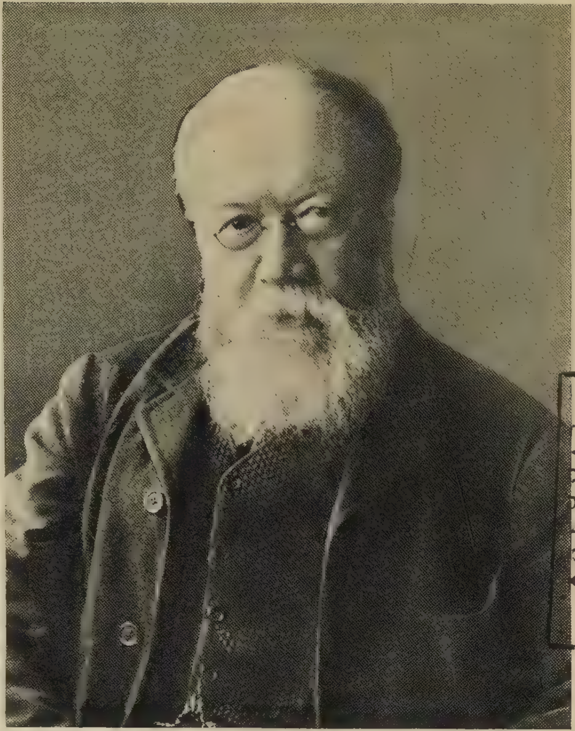
[1] This undesirable state of affairs was only eliminated when the telegraph wires were removed to a more distant route.

[2] Preece: *Electric Induction between Wires and Wires* (British Association Report, 1886).



WILLIAM HENRY PREECE
(1834-1913)

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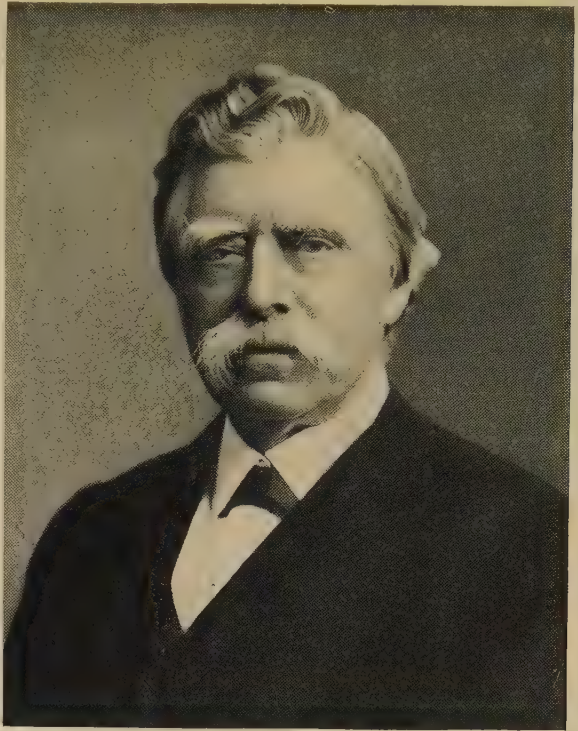

DAVID EDWARD HUGHES
(1830-1900)

were the same no matter whether the circuits were completely metallic or earthed at the end.

At Porthcawl, in South Wales, Preece's assistant, Gavey, carried out (1886) experiments on a wide stretch of sand. Two horizontal squares of insulated wire, 300 yards in length on each side, were laid side by side at varying distances apart. Then one of the squares was suspended 15 ft. in the air above the other, which was covered by water at high tide. The signals were found to be similar in strength no matter whether the intervening space was air or water or a combination of both.

As a result of these experiments Preece came to the conclusion that around the wire was a magnetic field that extended uninterruptedly through the earth as well as through the air. He suggested that if a circuit was arranged in a space beneath the ground, a current could be induced in it from a second circuit superimposed above ground.

In 1887 one of his assistants (A. W. Heaviside) tested the theory by arranging a circuit 2¼ miles in total length, in the form of an equilateral triangle along the galleries of Broomhill Colliery, Durham. The circuit was 360 ft. below the ground in a horizontal plane. Above the ground a second and similar circuit was placed, exactly over and parallel to the circuit down the pit. Telephonic conversation was easily established between the two circuits by induction.[1]

IV

In June, 1892, a Royal Commission was appointed to inquire into the practicability of electric communication between the shore and lighthouse and lightships. They sanctioned Preece to proceed with his proposed scheme, in order to test the theories he had formed as a result of his numerous experiments. The Bristol Channel was selected as being a suitable place for the experiment, for here are two islands, Flatholm and Steepholm, distant from Lavernock

---

[1] In 1922 experiments were carried out in America by the U.S.A. Bureau of Mines in conjunction with the Westinghouse Company in order to ascertain the suitability of wireless communication for rescue work. In these experiments continuous waves of 200 metres were used, and signals were distinctly heard through 50 ft. of strata, using single-turn frame aerials.

Point 3 and 5 miles respectively (Fig. 19). Communication was easily established over the shorter distance (3·3 miles), but between Lavernock and Steepholm (5·35 miles) conversation was found to be impossible, and Morse signals, although perceptible, were unreadable.

In March, 1898, Preece's system was permanently established between Lavernock Point and Flatholm, and was handed over to the War Office. A few months later S. Evershed's relays were added to work a call-bell, making the system " complete and practical ".

Preece also signalled in the Bristol Channel from a steam launch, which carried an insulated copper wire half a mile in length. One end was attached to a buoy so that it could be stretched either above the water or submerged. Near the shore signals were well received, both with the wire above and under the water. At a distance of a mile, however, signals were only received when the wire was out of the water. Preece concluded that the electro-magnetic waves of energy were either dissipated in sea-water, or that they were reflected from the surface of the water, as are rays of light.

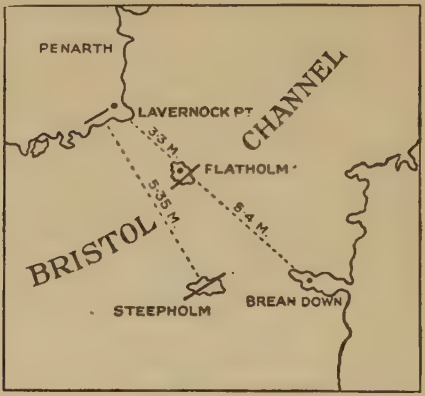

Fig. 19—Preece's system in operation across the Bristol Channel

Further experiments were made (in 1894) near Frodsham in Cheshire and in the Highlands at Loch Ness. Here it was found possible to send Morse signals, as before, and to carry on a telephonic conversation without wires over a distance of 1¼ miles. Indeed, sounds in the receiver were so loud that they were sufficient to "call up" the distant operator! A voltage of 140 (100 dry cells) was used in these latter experiments, two Bell telephones were used as receivers, and simple granular-carbon Deckert's microphones as transmitters. Experiments were also carried out successfully between Arran and Kintyre, across Kilbrannan Sound. Here two parallel lines, four miles apart, were used, together with two insulated wires laid along each coast, 500 ft. above sea-level and five miles apart.

V

So far transmissions had been only of an experimental nature, but on 30th March, 1895, the cable between the Isle of Mull and the mainland, about two miles away (near Oban), broke down. For a week, until the cable was repaired, communication was maintained without difficulty by laying an insulated wire, 1½ miles in length, along the ground from Morven on the Argyllshire coast, while on Mull the telegraph wire (about two miles in length) between Craignure and Aros was used. The ordinary commercial service was carried on by these means, about 160 public messages being exchanged, including a press telegram of 120 words.

Although Preece's system gave great promise, its limitations were soon realized. It was found that, as the distance between the two wires increased, the length of the wires had to be increased also; it was necessary for the length of each wire to be roughly equal to the distance between the two. Thus, although quite successful for communication over short distances, this system was useless for long distances on account of the great lengths of wire necessary for its successful working.

In 1899 Preece experimented in the Menai Straits, telephoning without wires from Anglesey to the lighthouse on the Skerries rocks, nearly three miles distant. This was accomplished by erecting wire, 750 yards in length, across the Skerries, and erecting on the Anglesey shore a second wire, 3½ miles in length. At each end of both wires copper plates were sunk in the sea. Telephonic and telegraphic communication was also established between the lighthouse on Rathlin Island (off the north coast of Ireland) and the mainland, eight miles away.

VI

As a result of his long research and numerous experiments, Preece arrived at definite conclusions in regard to the part played by the earth in electro-magnetic operations. The earth, he stated, acts simply as a conductor, and as a rule a very poor conductor, deriving its conducting property principally from the moisture it contains.[1] He stated it to be his opinion that

> " Although communication across space has thus been proved to be practicable in certain conditions, these conditions do not exist in the case of isolated lighthouses and lightships, cases for which it was specially desired to provide. The length of the secondary [wire] must be considerable, and, for good effects, at least equal to the distance separating the two conductors. Moreover, the apparatus to be used on each circuit is cumbrous and costly, and it may be more economical to lay an ordinary submarine cable.
>
> " Still, communication is possible even between England and France, across the Channel, and it may happen that between islands where the channels are rough and rugged, the bottom rocky, and the tides fierce, the system may be financially possible. It is, however, in time of war that it may become useful. It is possible to communicate with a beleaguered city either from the sea or on the land, or between armies separated by rivers, or even by enemies.
>
> " As these waves are transmitted by the ether, they are independent of day or night, of fog, or snow, or rain, and therefore, if by any means a lighthouse can flash its indicating signals by electro-magnetic disturbances through space, ships could find out their positions in spite of darkness and of weather. Fog would lose one of its terrors and electricity become a great life-saving agency."

That Preece realized that there might be great possibilities in wireless communication is clear from a striking address he delivered (23rd February, 1894) before the Royal Society of Arts. On this occasion he gave an account of his experiments extending over the previous ten years, and he gave rein to his imagination when he concluded by saying :

> " Although this short paper is confined to a description of a simple, practical system of communicating across terrestrial space, one cannot help speculating as to what may occur through planetary space. Strange, mysterious sounds are heard on all long telephone lines when the earth is used as a return, especially in the calm stillness of night.

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[1] Preece : *Signalling Through Space.*

Earth-currents are found in telegraph circuits, and the *aurora borealis* lights up our northern sky when the sun's photosphere is disturbed by spots. The sun's surface must at such times be violently disturbed by electrical storms, and as oscillations are set up and radiated through space, in sympathy with those required to affect telephones, it is not a wild dream to say that we may hear on this earth a ' thunderstorm ' in the sun.

" If any of the planets be populated with beings like ourselves, having the gift of language and the knowledge to adapt the great forces of Nature to their wants, then, if they could oscillate immense stores of electrical energy to and fro, in telegraphic order, it would be possible for us to hold commune by telephone with the people of Mars."[1]

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[1] *Electric Signalling Without Wires.* (See *Journal*, Society of Arts, 1894.)

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CHAPTER XII

D. E. HUGHES AND HIS WORK

UNTIL the time of Sir William Preece's experiments—indeed, practically until the close of the nineteenth century—two methods had been used by investigators in their attempts to solve the problem of wireless. The first was the system of Conduction, as represented by the system of Morse, and the second Induction, used—as we have seen—by several workers, but with most success by Preece. Towards the end of the nineteenth century, however, both these systems were superseded by a third, Radiation, made practicable by the discovery of the possibility of radiating electro-magnetic waves through space. Credit for the discovery of these waves is generally accorded to Professor Hertz, of Munich, but although he was certainly the first to publicly make known their existence, the waves were actually discovered and used some years earlier by a British scientist, D. E. Hughes, F.R.S. Although this is a well-established fact, the earlier discovery was at the time regarded as being so impossible that it was not generally announced.

David Edward Hughes (*b*, Plate XI) was born in London on 16th May, 1830. When seven years of age his family emigrated to Virginia, and he received his early education at St. Joseph's College, Bardstown, Kentucky. Here he attained some distinction in music and natural philosophy, but later his attention was directed to improving the telegraph. For two years he worked on improvements to the primitive form of type-printing telegraph then in use in America, and at 26 years of age invented an entirely new machine, which was taken up in America at once. Authorities in England would have none of it, however, but the French Government took up the invention with eagerness, and bestowed honours and riches upon the inventor—yet another instance of the truth of the saying : " A prophet is not without honour, save in his own country ".

After living some years in Paris, Hughes came to London and within a year invented his invaluable microphone, that at once took the place of the Bell transmitter and made the telephone a commercial success. Following up this invention, Hughes next brought out his inductance balance, and it was whilst investigating the curious behaviour of this apparatus that Hughes was led to make his most remarkable discovery.

In 1899 Hughes, in reply to a request to publish an account of his early wireless days, modestly wrote :

> " My past experiments in aerial telegraphy were completely unknown to the general public, and I feared that the few distinguished men who saw them had forgotten them, or at least had forgotten how the results shown them were produced. At this late date I do not wish to set up any claim to priority, as I have never published a word on the subject ; and it would be unfair to later workers in the same field to spring an unforeseen claimant to the experiments which they have certainly made without any knowledge of my work." [1]

Subsequently Hughes was again approached, however, and after further pressure gave an account of the events that led up to his ultimate discovery.

II

It was in 1879, when engaged on experiments with his microphone, together with his induction balance, that he noticed that at times he could not get a perfect balance, apparently through want of insulation in the coils. Investigation showed him that the real cause was some loose contact or microphonic joint excited in some portion of the circuit. He then applied the microphone, and found that it gave a current or sound in the telephone receiver, no matter if placed directly in the circuit or placed independently at several feet distance from the coils through which an intermittent current was passing. After numerous experiments he found that the effect was entirely caused by the extra current produced in the primary coil of the induction balance.

Further researches proved that an interrupted current in any coil gave out at each interruption such intense extra currents that the whole atmosphere in the room would have a momentary invisible charge, which became evident if a microphonic joint was used as a receiver with a telephone. This led him to experiment upon the best form of a receiver for these invisible electric waves, which he soon discovered passed through all obstacles, such as walls.

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[1] Fahie : *History of Wireless Telegraphy* (1899), Appendix D, p. 289.

He found that all microphonic contacts or joints were extremely sensitive. Those formed of a hard carbon such as coke, or a combination of a piece of coke resting upon a bright steel contact, were very sensitive and self-restoring. A loose contact between metals was equally sensitive, but would cohere, or remain in full contact, after the passage of an electric wave. He found also that, whilst an invisible spark would produce a thermo-electric current in the microphonic contacts (sufficient to be heard in the telephone in its circuit), it was far better and more powerful to use a feeble voltaic cell in the receiving circuit. The microphonic joint then acted as a relay by diminishing the resistance at the contact, under the influence of the electric wave received through the atmosphere.[1]

He found also that very sudden electric impulses, whether given out to the atmosphere through the extra current from a coil or from a frictional electric machine, equally affected the microphonic joint, the effect depending more on the sudden high potential effect than on any prolonged action. Thus, a spark obtained by rubbing a piece of sealing-wax was equally effective as a discharge from a Leyden jar of the same potential. The rubbed sealing-wax and charged Leyden jar had no effect until they were discharged by a spark, and it was evident that this spark, however feeble, acted upon the whole surrounding atmosphere in the form of waves or invisible rays, the laws of which he could not at the time determine.

In 1879, whilst making these experiments in wireless (or "aerial", as he called it) transmission, Hughes set himself two problems to solve: (1) What was the true nature of these electrical aerial waves, which seemed, whilst not visible, to oppose all idea of insulation and to penetrate all space to a

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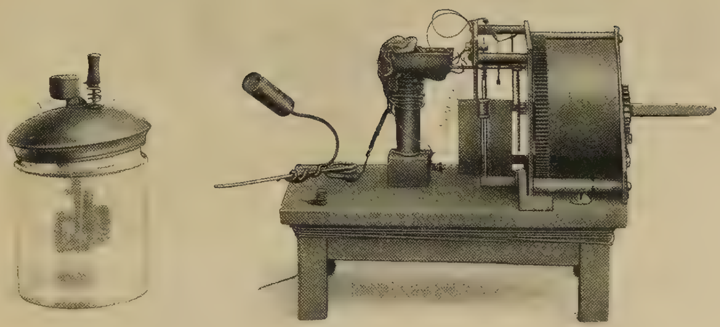
[1] On the left of A, Plate XII, is shown a microphonic detector, made by Hughes, and consisting of a steel needle hanging in light contact with a small circular hole in a block of carbon—one of the many forms of his experimental microphones.



HUGHES' CLOCKWORK TRANSMITTER AND (LEFT) DETECTOR (1878)

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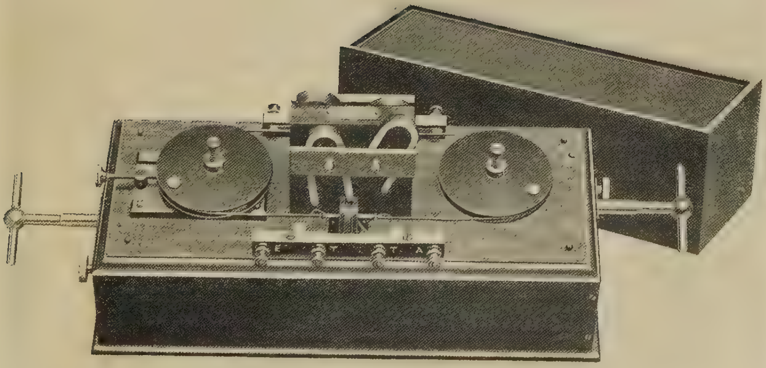

MARCONI'S MAGNETIC DETECTOR (1902)

distance undetermined. (2) To discover the best receiver that could act upon a telephone or telegraph instrument, so as to be able to utilize (when required) these waves for the transmission of messages.

> " The second problem came easily to me ", wrote Hughes, " when I found that the microphone, which I had previously discovered in 1877–8, had alone the power of rendering these invisible waves evident, either in a telephone or a galvanometer, and I do not know of anything approaching the sensitiveness of a microphonic joint as a receiver."

III

During his long-continued experiments on this subject, between 1879 and 1886, many curious phenomena came to Hughes's notice. He found that the effect of the extra current in a coil was not increased by having an iron core as an electro-magnet—the extra current was less rapid, and therefore less effective. A similar effect of a delay was produced by Leyden-jar discharges.

The material of the contact-breaker of the primary current was also found to have a considerable effect. Thus, if the current was broken between two pieces of carbon, no " aerial waves " could be detected, even at short distances of a few feet. The extra current from a small coil without iron was as powerful as an intense spark from a secondary coil. At that time his experiments were confined to the use of a single coil of his induction balance, charged by six Daniell cells. He found that with greater battery power the extra current invariably destroyed the insulation of the coils.

In his experiments Hughes transmitted signals from one room to another in his house in Portland Street, London. As the greatest range possible in these circumstances was about 60 ft., he obtained a greater range by setting " the transmitter in operation and walking up and down Great Portland Street with the receiver in my hand and with the telephone to my ear ". We are not told what passers-by thought of the learned scientist, apparently wandering aimlessly about with a telephone receiver held to his ear, but doubtless they had their own ideas! Hughes found that the strength of the signals increased slightly for a distance of 60 yards and then gradually diminished, until at 500 yards they no longer could be heard with certainty.

IV

Between December, 1879, and November, 1888, several leading scientists were invited to see the results obtained. Those who witnessed the " aerial transmissions ", as Hughes named them, included Sir W. H. Preece and Sir William Crookes (December, 1879), Professor Dewar (November, 1888), and several others. " They all saw experiments . . . by means of the extra current produced from a small coil and received upon a semi-metallic microphone, the results being heard on a telephone in connection with the receiving microphone. The transmitter and receiver were in different rooms and about 60 ft. apart."

Referring to the experiments he had witnessed (in December, 1879) at Hughes's house, Sir William Crookes wrote (in 1892) :

> " Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog ; but electrical vibrations of a yard or more in wave-length will easily pierce such media, which to them will be transparent. Here is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfilment. At present experimentalists are able to generate electric waves of any desired length and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in any given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another.
>
> " What remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the shortest, say a few feet, that will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles. Secondly, more delicate receivers that will respond to wave-lengths between certain defined limits and be silent to all others. And thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate

as when the rays to be picked up are simply radiating into space and fading away according to the law of inverse squares.

"At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send out the waves in all directions, and it would therefore be possible for any one living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, 50 yards. I assume here that the progress of discovery would give instruments capable of adjustment, by turning a screw or altering the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to 50-yard waves, the transmitter might emit, and the receiver respond to, rays varying between 45 and 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.

"This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches that are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now telegraphing without wires is possible within a restricted radius of a few hundred yards. Some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described."[1]

V

On 20th February, 1880, Hughes's experiments were witnessed by Mr. Spottiswoode, the President of the Royal Society, and his two secretaries, Professors Huxley and Sir G. G. Stokes. The experiments were most successful, and at first the distinguished scientists seemed astonished at the results obtained. After three hours' demonstration, however, Professor Stokes said he could not accept the inventor's theory that the results were due to electric waves, as all the results could be explained by known electro-magnetic induction effects.

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[1] *Some Possibilities of Electricity*, in the *Fortnightly Review*, February, 1892, p. 173.

> " I was so discouraged ", wrote Hughes, " at being unable to convince them of the truth of these aerial electric waves that I actually refused to write a paper on the subject [for the Royal Society] until I was better prepared to demonstrate the existence of these waves. I continued my experiments for some years, in the hopes of arriving at a perfect scientific demonstration of the existence of aerial electric waves, produced by a spark from the extra currents in coils, or from frictional electricity or from secondary coils."

Thanks to the discouragement of Sir George Stokes, Hughes's great discovery was lost to the world. Indeed, had not Sir William Crookes written his article on the subject, which caused the scientific world to demand the name of the author of the seemingly incredible experiments that revealed the " bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly apparatus ", we should probably have never heard of Hughes's experiments in this connection, for even in 1899 he was unwilling to publish any details of his work, as we have already mentioned.

From his microphone and other inventions Hughes realized a considerable fortune, and it is pleasing to record that when he died (in London, 22nd January, 1900) he left about £400,000 to the London hospitals. Hughes was a singular genius and brilliant experimenter. Of him Sir Oliver Lodge has said :

> " He was a man who ' thought with his fingers ', and who worked with the simplest home-made apparatus—made of match-boxes and bits of wood and metal, stuck together with cobbler's-wax and sealing-wax. Such a man constantly working is sure to come upon phenomena inexplicable by orthodox science. And orthodox science is usually too ready to turn up its nose at phenomena which it does not understand, and so thinks it simplest not to believe in." [1]

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[1] *Wireless Weekly*, 5th September, 1923.

CHAPTER XIII

CLERK-MAXWELL PREDICTS, AND HERTZ DISCOVERS, ELECTRO-MAGNETIC WAVES

ALTHOUGH he did not know it, there is no doubt that Hughes was using electro-magnetic waves, the existence of which was subsequently announced in 1888 by Hertz and brilliantly predicted by mathematical analysis in 1864 by Clerk-Maxwell, of Cambridge.

James Clerk-Maxwell (*a*, Plate XIII), " one of the essential founders of wireless communication ",[1] was born at 14, India Street, Edinburgh, on 13th November, 1831. His father (who died in 1856) was a lawyer, interested in science as a hobby, and he devoted himself to the education of his son, his only child. He was a brother of Sir George Clerk, of Penicuik, Midlothian, and took the surname Maxwell on inheriting some property.

James spent his childhood at his father's country house, " Glenlair ", near Dalbeattie, Castle Douglas, his mother, a Northumberland lady, having died when he was eight years of age. At the age of 10 he was sent to Edinburgh Academy, where he was nicknamed " Dafty ". For some years he showed no promise of the great genius that was his, although he surprised his schoolfellows, and delighted his father, by winning a prize for mathematics. When 15 years of age he drew some ovals that were so curious that they were brought to the notice of Professor Forbes, with the result that James communicated a paper to the Royal Society of Edinburgh, *On the Description of Oval Curves*. In 1847 he entered the University of Edinburgh and studied many branches of science, including magnetism and the polarization of light. No doubt his attention had been drawn to the latter subject when on a visit (in 1848) to Nichol, the inventor of the prism that bears his name, when Maxwell saw, for the first time, the beautiful chromatic effects obtained by polarized light.

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[1] Sir Oliver Lodge at Finsbury Technical College, 1925.

Although his father wished him to be a lawyer, James said he was more interested in " laws of another kind ", and at last he had his way. In October, 1850, he went up to Cambridge as an undergraduate at Peterhouse, moving to Trinity in the following December. In April, 1852, he was elected a scholar of his college, and two years later graduated as Second Wrangler, being elected a Fellow of Trinity in 1855. He was placed on the staff of lecturers, and in the following year was appointed Professor of Natural Philosophy in Marischal College, Aberdeen. Four years later, on the College becoming amalgamated with King's College to form the University of Aberdeen, he was appointed Professor of Natural Philosophy in King's College, London, which post he resigned in 1865. Six years later he was appointed first Professor of Experimental Physics at Cambridge, and delivered his inaugural lecture 25th October, 1871.

II

Clerk-Maxwell's life-work commenced at Cambridge, after he had won his fellowship. He had determined to master mathematics before studying electricity, and on entering Trinity he proceeded to acquaint himself with the existing knowledge on the subject. He closely followed Faraday's work, entered into a correspondence with the great man, and in December, 1855, read a paper before the Cambridge Philosophical Society on *Faraday's Lines of Force* containing the germs of his future discoveries.

Faraday had suggested that the electrical interaction between two bodies was conveyed by lines of force through the ether and was not merely action at a distance. The difficulty was, however, that Faraday's theory required an ether that was entirely different from the theoretical medium developed by the great mathematicians of the old school in connection with the " elastic-solid " theory of light. What Clerk-Maxwell set out to prove was that there was only one medium in which electrical lines of force acted. He showed that not only were light and electric waves identical in nature, but that they were actually different forms of electro-magnetism.

Faraday's researches caused Clerk-Maxwell "not to attempt to establish any physical theory of a science in which I have hardly a single experiment, but to show how by strict application of the ideas and methods of Faraday, the connection of the very different order of phenomena that he has discovered may be placed before the mathematical mind". He suggested that electrical and magnetic effects do not arise from the attractions of electrical or magnetic matter distributed over the surfaces of conductive or magnetic bodies. Instead, he believed them to be the means by which changes of some unknown description in the ether, or in some of its properties, become known to us. In consequence of these changes energy is stored up in the ether, he thought, and electric or magnetic forces are one form of the manifestation of changes in the distribution of energy.

He developed similar ideas in his great paper *On a Dynamical Theory of the Electro-magnetic Field*, read before the Royal Society (December, 1864), and he applied dynamical equations, in the generalized form given to them by Lagrange, to the problems of electro-magnetism. He pointed out that in dealing with these problems "we are led to the conception of a complicated mechanism capable of a vast variety of motions, but at the same time so connected that the motion of one part depends, according to definite relations, on the motion of other parts. . . . Such a mechanism must be subject to the laws of dynamics".

He showed that electro-magnetic action must travel through space at a definite rate in waves, and that these waves must consist of disturbances that are transverse to the direction in which the waves are propagated. In the course of his work he made the remarkable statement that the ether must be able to transmit electrical waves with a speed exactly equal to that of light, and that therefore any medium explaining electrical action could also be held to explain light. The result was his brilliant achievement in the foundation of the electro-dynamic theory of light, which showed that the dynamical principles devised by Galileo and Newton for dealing with ordinary matter could not apply to light, which was to be explained solely and wholly in terms of electricity and magnetism.

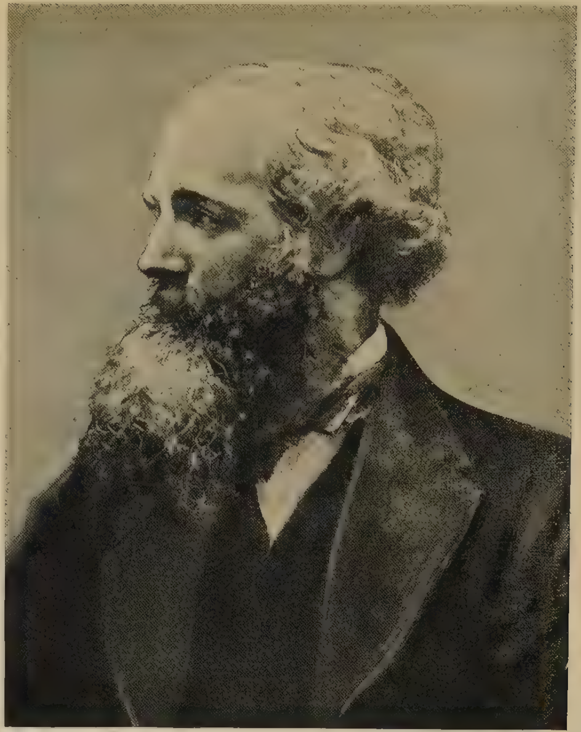
In 1857 Clerk-Maxwell had won a prize in connection with an abstruse problem regarding Saturn's ring system. This prize had been founded in memory of J. C. Adams, who is remembered as the discoverer of the planet Neptune. Certain irregularities had been noticed in the movements of Uranus, and Adams had mathematically worked out not only the mass of the disturbing body, but had also indicated the exact position in the skies where the hypothetical planet would be found on a certain day. The story of the discovery of the planet, subsequently named Neptune, according to Adams's prediction, is one of the most brilliant and romantic incidents in the history of Astronomy.

It was a curious coincidence that Clerk-Maxwell, the winner of the Adams Prize, should subsequently himself perform a somewhat similar task to the mathematical discovery of Neptune, but on a considerably larger scale. The theory he had advanced required it to be supposed that electrical action at a distance was produced by a train of electrical waves. Not only did he work out the properties of these unknown waves, but he gave their measurements and predicted amongst other things that if these electric waves could be generated they would travel with the velocity of light. He also showed that the refractive index of a substance was intimately related to its dielectric coefficient, and that conductors of electricity must be opaque to light. He demonstrated that the ether had two great characteristic constants of value, the electric constant, which Faraday called K, the other, the magnetic constant, that Kelvin called U. Clerk-Maxwell realized the impossibility of determining the value and nature of these constants, but was able to measure their product, which he showed to be equal to the reciprocal of the square of the velocity of light.

His theory was not accepted until 1873, when his original paper was subsequently enlarged and expanded into his famous *Treatise on Electricity and Magnetism*, on the second edition of which he was engaged when he died. Scientific men were very reluctant to abandon the old idea of an "electric-solid" ether in favour of Clerk-Maxwell's alternative, and even so enlightened an authority as Lord Kelvin refused to accept the new theory. Opposition was finally crushed, however, when

PLATE XIII

HEINRICH RUDOLF HERTZ
(1857-1894)



JAMES CLERK MAXWELL
(1831-1879)

Hertz discovered the electric waves, the behaviour and measurement of which, as we shall shortly learn, were found to fulfil Clerk-Maxwell's prediction in every respect.

III

Clerk-Maxwell did not live to see the vindication of his brilliant theory, for in the summer of 1879, whilst on a visit to "Glenlair", his Scottish home, he became seriously ill. Although he was able to return to Cambridge in October, he never recovered, and died on 5th November at the early age of 48.

He is described as having been a man loved and honoured by all who knew him. To his pupils he was the kindest and most sympathetic of teachers—to his friends he was a charming companion—brimful of fun, the life and soul of a Red Lion dinner at the British Association meetings, yet in due season grave and thoughtful. He had a keen interest in problems that lay outside the domain of his own work, and throughout life was a stern foe to all that was superficial or untrue.

In addition to the work that has earned him undying fame, he investigated (in 1855) colour phenomena and the theory of colours in regard to colour-blindness. He also investigated the effects of certain combinations of colours by means of rapidly rotating discs, summing up his results in a paper, *The Theory of Compound Colours*, read before the Royal Society in March, 1860. In this paper he suggested that the three primary colours correspond to three different sensations in the eye, and that the absence of one of the three primary sensations was probably the cause of colour-blindness, as in normal vision an object appears of definite colour because it excites sensations in correct proportions. For this work Maxwell was awarded (in November, 1860) the Rumford Medal.

We have already mentioned his work in connection with Saturn's rings, for which he was (in 1857) awarded the Adams Prize. He read papers on the kinetic theory of gases and the constitution of matter (*Molecules*) before the British Association at Bradford in 1860. In 1879 he edited for publication the *Electric Researches of Henry Cavendish* (written 1771–81) from the original manuscript. He also wrote a textbook on heat and a treatise on *Matter and Motion.*

Clerk-Maxwell did not confine his attention solely to the theoretical side of electricity, realizing—as did Lord Kelvin—that accurate experiment was essential to form a foundation of his theory. He experimented (in 1862) on behalf of the newly formed Electrical Standards Committee of the British Association in regard to the standard of resistance, and also in regard to the velocity of propagation of electro-magnetic waves. It must for ever remain a matter of surprise that neither he nor any member of the band of brilliant young physicists who surrounded him at the Cavendish Laboratory ever furnished experimental proof of his theoretical electric waves.

IV

In order that we may fully appreciate the theoretical work of Clerk-Maxwell and the practical work of Hertz, who experimentally verified his predictions, we may profitably consider for a moment the theory held in their day regarding the nature of light.

There are innumerable records of ancient speculations into the properties of light, but the first tangible theory was propounded by Sir Isaac Newton. He considered that the sensation of light was due to inconceivably minute particles, which he called " corpuscles ", impinging against the retina. These particles, he thought, were emitted from luminous bodies and projected in all directions into space with incomparable velocity. This theory, called the Corpuscular Theory, was subsequently found to be unsatisfactory. Not only were there inherent improbabilities but also fatal objections to supposing that light consists of a multitude of minute bodies. Serious difficulties were encountered, for instance, when an attempt was made to explain interference, diffraction, and polarization. Also, according to Newton's theory, the speed of light would obviously be greater in a denser medium, whereas Foucault showed experimentally that exactly the reverse is the case.

The Corpuscular Theory was replaced by the Undulatory Theory, propounded by Thomas Young (1773–1829) and communicated to the Royal Society 1801–3. This theory supposed that light consists of undulations, or waves, transmitted by a medium, the "luminiferous ether", so called because it was then known to be capable only of transmitting light. This medium was believed to fill all space, including inter-molecular space. A ray of light consisted of a wave motion in this medium, the direction of vibration being perpendicular to the direction of the ray. The theory assumed the existence of a medium (now generally known as the ether) that had qualities analogous to density and elasticity. Although Young's Undulatory Theory explained practically all the known facts regarding light, it was not accepted [1] until thirteen years later, when his magnificent discoveries were confirmed by the brilliant Frenchman, Fresnel.

This briefly was the position when Clerk-Maxwell propounded (in 1864) his theory of electro-magnetic waves propagated with the speed of light. He assumed that the material universe "floats" in one all-pervading ether, and that if a disturbance of electrical equilibrium is produced at any place, it must be propagated through space in the form of waves with a velocity equal to that of light.

V

Clerk-Maxwell's discovery was made by one of those amazing achievements only possible to a great mathematician and physicist. He did not discover how to generate the ether waves nor how to detect them, and although it was left to Hertz to supply the full experimental proof that Maxwell and his followers were confident would be forthcoming sooner or later, it must not be forgotten that the waves were first discovered (in 1875) by Professor Elihu Thomson. He was experimenting at Philadelphia with an induction coil, one terminal of which was connected to a water pipe and the other to an insulated metal still. He found that, by placing the point of a lead pencil near to the brass knob of the laboratory door, delicate sparks passed. He first traced these sparks at some 60 ft. from the coil, and proceeding to the sixth

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[1] Largely owing to a bitter attack on Young by Lord Brougham, in defence of Newton.

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floor, some 100 ft. away, found they were also visible. This discovery was made 12 years before Hertz made public his work, and no doubt Thomson would have forestalled him had his interest not been diverted by other studies.[1]

Heinrich Rudolf Hertz (*b*, Plate XIII), perhaps the most brilliant experimentalist and the ablest physicist the world has yet seen, was born at Hamburg on 22nd February, 1857. During his schooldays he cherished the ambition to become an engineer, and when 20 years of age studied at Munich with this profession in view. He soon found that he was more interested in the physical theories on which practical mechanics are based than in the practical details of the subject. Accordingly, in less than a year, he changed his plans, and well it is for science and the world in general that he did so. During the winter of 1877 he read original treatises by the famous physicists of the past, attended lectures on experimental physics, and experimented to the full extent of his time. His studies were thorough and his interest keen, and it is no wonder that when he went to Berlin University (in October, 1878) he attracted the attention of leading experts, and was at once placed on original research work. He won a prize for the best solution of a difficult electrical problem,[2] and became the most notable pupil of Helmholtz, a great teacher, and a giant in many branches of science, including mathematics, physics, and chemistry.

From 1880–3 he acted as assistant to Helmholtz, and carried out many difficult and original researches in physics.[3] In 1883 he went to Kiel as Professor of Theoretical Physics, and devoted some time to a study of Clerk-Maxwell's electromagnetic theory. From this he learned that if a conductor is electrically charged or discharged with sufficient suddenness, it must emit electrical waves into the ether, because the charge given to it will not settle down instantly, but will surge to and fro for some time, and these surgings produce waves in the ether.

[1] For details see *General Electric Review*, vol. xxiii, No. 3 (March, 1920).

[2] His paper was entitled *The Kinetic Energy of Electricity in Motion.*

[3] Sir Oliver Lodge has told us (*Wireless Weekly*, 12th September, 1923) how he made the acquaintance of Hertz in 1881, when seeing Helmholtz in Berlin. Helmholtz thought highly of his demonstrator. Hertz, who was not fully acquainted with Clerk-Maxwell's theory at the time of Sir Oliver's visit, " could speak English and was very friendly ".

As we have already seen, Clerk-Maxwell not only predicted the existence of the waves but even calculated their rate of travel and their length, and showed that they would move more slowly in glass and water than in air. In 1883, at the Southampton Meeting of the British Association, Fitzgerald suggested that the oscillatory discharge of a Leyden jar might be used for the production of electric waves, if a means for detecting them could be devised.

Although all this and other essential theoretical data were known, the existence of the waves remained unproved until 1888. In that year Hertz announced to the world his epoch-making discoveries, which brilliantly demonstrated the truth of Clerk-Maxwell's conception.

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VI

In his collected papers [1] Hertz tells us that his interest in the study of electrical oscillations originally commenced with the announcement of the Berlin prize of 1879, to be awarded for an experimental proof of a relation between electrodynamic forces and dielectric polarization in insulators. Helmholtz suggested to Hertz that he should take up the inquiry, and he did so, only to find that the then known oscillations were too slow to offer any promise of success. Although he abandoned the research for the time being, he remained on the look-out for phenomena in any way connected with the subject.

At the time of his discovery, Hertz was Professor of Physics at the Karlsruhe Polytechnic, having been appointed in 1885, and it was here that the discovery was made accidentally. Hertz had found, amongst the laboratory apparatus at Karlsruhe, an old pair of so-called Riess's, or Knochenhauer's, spirals. These were short, flat coils of insulated wire, with the turns all in the same plane. One day, at a lecture, he was experimenting with these coils and a Leyden jar, and noticed that the discharge of the jar through one of the coils induced an appreciable current in the other coil (although the jar was a very small one), provided that there was a spark-gap in the inducing coil. This accidental discovery of the "effective spark-gap" started him on the track of his subsequent successes.

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[1] *Electric Waves*, London, 1893.

At first he did not seem to realize what his results meant, and in describing his experiments he did not use the words "electric waves", but spoke of "the outspreading of electric force". The title "electric waves" was attached to Hertz's book at the suggestion of Lord Kelvin when it was subsequently translated.

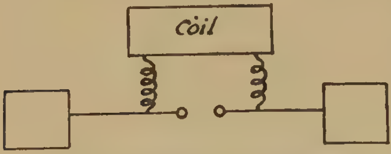

FIG. 20—HERTZ'S OSCILLATOR

The apparatus, remarkable for its simplicity, used in his experiments was called an "oscillator", and consisted of two parts—the "exciter" (Fig. 20) and the detector, or "resonator" as Hertz called it (Fig. 21). The exciter was formed by mounting a metal plate at the ends of two metal rods, the other ends of which terminated in metal balls. These balls were separated by a distance of about half an inch. At first the rods were connected to a Leyden jar, but in later experiments to the terminals of the secondary winding of an induction coil. By these means they were charged so that a spark was caused to jump across the gap separating the two balls. The resonator was formed by a wire, bent to a circular shape, but having a small gap, the ends terminating in two small metal balls. This wire ring was placed a short distance away from the exciter. When the latter was set in action, sparks were seen to jump across the gap in the resonator, although the latter was not connected in any way with the oscillator.

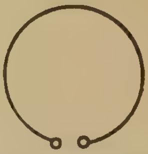

FIG. 21—HERTZ'S RESONATOR

The power of the waves to generate sparks in an insulated conductor upon which they impinged seems to have surprised Hertz himself, as well as others who subsequently experimented in the same field. Sir Oliver Lodge calculated that the radiating power of even a small Hertz oscillator was 100 h.p. while it lasted. The duration was excessively short, for practically all the energy was expended in a single swing, requiring about 100-millionth of a second, but its power of producing small sparks was explained.[1]

VII

With the " exciter " to propagate the electric waves and the " resonator " to detect them at a distance, Hertz reproduced all the phenomena of light one after another, in corresponding electro-magnetic effects, and thus completely demonstrated the identity of light and electricity. He worked with extraordinary skill, both experimentally and mathematically, and quickly perceived that not only could Clerk-Maxwell's theory be applied to his discovery, but also that the theory might be elaborated in detail so as to include the whole range of his phenomena. By laborious and difficult experiments he came to know all about his new form of electric waves, publishing his results in a rapid succession of papers addressed to the Berlin Academy of Sciences between 10th November, 1887, and 13th December, 1889.

Sir Oliver Lodge paid a high tribute to the genius of Hertz when he said : " We know not which to admire most—his experimental skill when working with a tiresome and irritating mode of detection, or his mathematical thoroughness in ascertaining the laws of the propagation ". This was perhaps his most difficult task ; in his paper (1888) *Action of a Rectilinear Electric Oscillation on a Neighbouring Circuit*, he pointed out that when sparks passed rapidly at the exciter a rectilinear oscillation radiated into surrounding space. The resonator, the spark-gap of which was adjustable by means of a micrometer screw, was brought into all kinds of positions with respect to the exciter, and the results were carefully studied and accurately measured. They were found to obey a law of radiation that Hertz found was none other than the corresponding law in optics.

In his next paper, *Velocity of Propagation of Electrodynamic Actions*, he gave experimental proof of what had until then been only a theoretical fact—that the velocity of electric waves in air is the same as that of light. He was puzzled to find, however, that the velocity in *wires* was much less—in the ratio of 4 to 7. Sarasin and de la Rive, of Geneva, subsequently repeated the Hertzian experiment with larger apparatus, using the large turbine hall of the Geneva Waterworks, and found the rate of propagation to be the same along wires as in air.[1] It was then shown that the deviations from theory had been caused by the walls of Hertz's laboratory, which reflected the electric waves impinging on them and caused interferences in the observations.

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[1] *Phil. Mag.*, July, 1889, p. 54.

In his paper, *Electro-dynamic Waves and their Reflection*, Hertz further developed this point. A screen of zinc plate, 8 ft. square, suspended opposite the exciter, reflected the electric waves from it, and these, on meeting the direct waves, produced interference in the form of stationary waves with nodes and loops. When the detector was moved between the screen and the exciter, the sparks disappeared at certain points and reappeared at others. There was found to be a periodically alternating effect corresponding to nodes and loops of electric radiation. This clearly proved that the radiation was of an undulatory character and the velocity of its propagation finite.

Continuing his experiments, Hertz showed that the electromagnetic waves vary in length from an inch to 1,000 miles. In his next paper, *Electric Radiation*, he not only proved that their rate of travel was identical with that of light waves, but showed that they possess all the fundamental properties of light, differing from them only in pitch and penetrating power. He showed that they are propagated in straight lines; that they cannot pass through metals; that they may be reflected, refracted, and even polarized. He also produced "electrical shadows" by setting up metallic screens. A more complete confirmation of Clerk-Maxwell's theory by experimental demonstration could not have been given. All this important experimental work, which was carried out in a small room, demonstrated to the world beyond all doubt that light and electricity are identical in their essential details.

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[1] *Comptes Rendus*, 31st March, 1891, and 26th December, 1892. See also the *Electrician*, vol. xxvi, p. 701, and vol. xxx, p. 270.

VIII

The discovery of the Hertzian waves had scarcely been announced when Huber, a civil engineer of Munich, suggested to Hertz that they might be used as a means of communicating without wires. Remarkable though it seems, Hertz does not seem to have realized the full significance of this suggestion, which he at once discouraged. He believed that the alternations of current in the telephone were too slow, in comparison with the period of the electro-magnetic oscillations, for it to be utilized in conjunction with them. Although the idea was thus left to others to develop, and Hertz missed an opportunity of adding still further to his fame, he could scarcely have answered Huber other than he did, for at that time there was no sufficiently sensitive means of detecting electro-magnetic waves of low intensity, the discovery of the microphonic contacts by Hughes having been lost sight of.

IX

Hertz was a modest man with a kind and charming nature. He made no attempt to turn to practical use a discovery that was to him not a commercial proposition, but simply an amazing confirmation of an abstruse mathematical theory.

> " I should like to say ", said Sir Oliver Lodge in a lecture at the Royal Institution (1st June, 1894), " that the enthusiastic admiration for Hertz's spirit and character felt and expressed by students and workers who came in contact with him is not easily to be exaggerated. Never was a man more painfully anxious to avoid wounding the susceptibilities of others ; and he was accustomed to depreciate the prominence given to him by speakers and writers in this country, lest it might seem to exalt him unduly above other and older workers among his own sensitive countrymen."

Following his great discoveries, Hertz was appointed (in 1889) Professor of Physics at Bonn, where he continued his studies of electrical discharges through gases, a subject in which he had interested himself when working under Helmholtz. In one of his experiments he found a mysterious and visible ray and narrowly missed discovering the X-ray, which actually streamed unnoticed from his vacuum tubes during some of his experiments !

It was a great loss to science when Hertz died (at Bonn, on 1st January, 1894) at the early age of 37, and before his pioneer work had borne the full fruit of Marconi's subsequent adaptation. But, as Sir Oliver Lodge has truly said, he " effected an achievement that will hand his name down to posterity as the founder of an epoch in experimental physics ".

CHAPTER XIV

RIGHI IMPROVES THE TRANSMITTER; BRANLY INVENTS THE COHERER-DETECTOR; LODGE'S EARLY WORK; POPOFF INTRODUCES THE ELECTRICAL "TAPPER"

THE discoveries of Hertz became the subject of experiment in many laboratories in different parts of the world and soon further additions to our knowledge were made. Hertz's waves, for instance, were many metres in length, and it does not seem that he ever worked with waves of less than 30 centimetres. It was not long before shorter waves were produced and also improved methods of propagating and detecting the waves.

Some of the most important developments at this time were made by Augusto Righi (*a*, Plate XIV), Professor of Physics at Bologna University.

In a speech at Archiginnasio di Bologna in 1926, Marconi said:

> "I wish once more to record with deep admiration and reverent affection the great figure of Augusto Righi, who, with his genius and his indefatigable effort, did so much for the study of electric waves and to wrest secrets from Nature. His clever and classical work on the optics of electrical oscillations accomplished here at Bologna led to results which, from the walls of his laboratory, became the admiration of the students of physical sciences throughout the world, to the permanent benefit of mankind."

Righi, who was a native of Bologna, was born on 27th August, 1850, and died there on 8th June, 1920. He was a scientist of some distinction and, as we shall see later, aroused in one of his pupils—Marconi—a great interest in the Hertzian waves. Soon after Hertz had announced the discovery of the electro-magnetic waves, Righi commenced to investigate them, paying particular attention to their optical properties. He embodied his results in a treatise, not yet published in English, entitled *Optice Elettrica* (1897).

By using exciters with very small spheres, he was able to propagate waves of 2·5 centimetres. Generally speaking, he found that the smaller the exciting spheres, the shorter the waves.[1] Carrying the matter to its extreme and imagining the ultimate atom to be used, we should get waves the length of which correspond approximately to light waves.

Righi also effected a considerable improvement in Hertz's "exciter" by replacing his hollow spheres with solid metal balls, which enabled the waves to be transmitted to nearly double the distance.

Hertz had found that the spheres quickly oxidized and the roughened surfaces caused their action to become irregular. This necessitated the spheres being frequently cleaned and their surfaces polished. To overcome this difficulty E. Sarasin and L. de la Rive, of Geneva, immersed the spheres in olive oil. The sparks were then found to be greatly strengthened, but the oil was found to carbonize quickly. Righi further improved on this suggestion by placing the metal balls in an ebonite frame and filling the spark-gap with vaseline oil, thickened by the addition of ordinary vaseline and contained in a parchment envelope.

Righi found that this "liquid cushion" seemed to have a heightening effect on the electric potential and also that it had a regularizing effect, making the production of the waves more uniform. He also found oxidization very materially reduced, and even after working for a long time, when the vaseline had become black and the surfaces of the balls were covered with a deposit of carbonized vaseline, the apparatus continued to perform satisfactorily.

Righi also introduced what he considered to be an improved detector. Hertz's "rectifier" had consisted of simply a wire bent in the form of a circle, cut in one place and the ends terminating in small metal knobs, between which the sparks appeared. Righi's detector consisted of thin bands of quicksilver, as used for mirrors, rendered discontinuous by cross-lines lightly traced with a diamond.

Righi resembled Hertz, and other modest workers, in his dislike of publicity. "Righi's friends", wrote A. Trowbridge,

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[1] By using minute spheres of platinum Professor Chunder Boze, of Calcutta, was able to produce waves of only 6 millimetres.

"appear to have been jealous lest he should fail to receive proper credit for his part in making wireless communication possible. But not so Righi himself, who cared little for popular applause and actually enjoyed a fuller measure of it in his own country than ordinarily falls to the lot of a pure scientist."[1]

II

Before the Hertzian waves could be turned to practical use for wireless communication, and before any system of wireless could become commercially possible, it was evident that some more delicate apparatus than the somewhat crude resonator spark-gap was necessary for the detection of the waves. Such an apparatus was speedily forthcoming, and in its final form was given to the world by Professor Branly, of France.

Edouard Branly (*b*, Plate XIV) was born at Amiens on 23rd October, 1844, and was educated at the Lycée de St.-Quentin, and later at the Lycée Normale Supérieure, Paris. In 1873 he took his degree of Doctor of Science and became Professor of Physics at the Catholic University, Paris, a position that he holds to-day. In spite of his arduous lecturing duties, Professor Branly has never ceased to devote himself with the greatest enthusiasm to scientific research, and even to-day, at over 80 years of age, he is to be found at work in his beloved laboratory. "I am not yet too old to work," he said in a recent interview, "and very soon I hope to finish my present research. In the meantime, I cannot say anything about it."

III

To trace the sequence of events that led Branly to his ultimate discovery it must be mentioned that in 1850 Guitard had noticed that when dusty air was electrified from a point, the dust particles tended to cohere into strings or flakes.[2]

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[1] *Science*, 6th August, 1920, vol. lii, p. 122.

[2] Lord Rayleigh (in 1879) investigated similar action in meteorological phenomena, such as the formation of snowflakes under the influence of atmospheric electrification; the cohesion of small raindrops into larger ones near a charged cloud, etc.

This long-forgotten observation seems to have been rediscovered in 1866 by S. A. Varley, who made the first practical application of this principle of cohesion by embodying it in the construction of his lightning protector for telegraphic apparatus.

In a paper read before the British Association at Liverpool (1870) he tells how he had observed the very great resistance afforded to electric currents of moderate tension by a loose mass of dust. " With a tension of, say, fifty Daniell cells, no appreciable quantity [of current] will pass across the dust of blacklead or fine charcoal powder loosely arranged, even when the battery poles are approached very near to one another." He found that metallic dust interposed between two conductors decreased in resistance as the electrical pressure increased—in other words, metallic dust is a bad conductor of ordinary electric currents, but when subjected to high-frequency currents it instantly becomes a good conductor.

> " If the tension be increased to, say, two or three hundred cells, the particles arrange themselves by electrical attraction close to one another, making good electrical contact, and forming a channel or bridge through which the electric current freely passes. When the tension was still further increased to six or seven hundred cells the author found the electricity would pass from one pole to the other through a considerable interval of the ordinary dust that we get in our rooms, and which is chiefly composed of minute particles of silica and alumina mixed with more or less carbonaceous and earthy matters.
>
> " Incandescent matter offers a very free passage to electrical discharge, as is indicated by the following experiments. The author placed masses of powdered blacklead and powdered wood charcoal in two small crucibles; no current would pass through these masses whilst they were cold, however close the poles were approached, without actually touching. The battery employed in this experiment was only twelve cells. The crucibles were then heated to red heat, and electricity freely passed through the heated powder; and on testing the resistance opposed by the heated particles, placing the poles 1 in. apart, and employing only six cells, the average resistance opposed by the blacklead was only four British Association units, and that opposed by the wood charcoal five units. The average resistance of a needle telegraph coil may be taken at 300 units, or ohms as they are now termed.
>
> " These observations go to show that an interval of dust separating two metallic conductors opposes practically a decreasing resistance to an increasing electrical tension, and that incandescent particles of carbon oppose about $\frac{1}{60}$th part of the resistance opposed by a needle telegraph coil. Reasoning upon these data, the author was led to

construct what he terms a ‘ lightning-bridge ’, which he constructs in the following way :

“ Two thick metal conductors terminating in points are inserted usually in a piece of wood. These points approach one another within about $\frac{1}{18}$th of an inch in a chamber cut in the middle of the wood. This bridge is placed in the electric circuit in the most direct course that the lightning can take, and the space separating the two points is filled loosely with powder, which is placed in the chamber and surrounds and covers the extremities of the pointed conductors.

“ The powder employed consists of carbon (a conductor) and a non-conducting substance in a minute state of division. The lightning finds in its direct path a bridge of powder, consisting of particles of conducting matter in close proximity to one another ; it connects these under the influence of the discharge, and throws the particles into a highly incandescent state. Incandescent matter, as has been already demonstrated, offers a very free passage to electricity, and so the lightning discharge finds an easier passage across the heated matter than through the coils.

“ The reason a powder consisting entirely or chiefly of conducting matter cannot be safely employed is that, although in the ordinary condition of things it would be found to oppose a practically infinite resistance to the passage of electricity of the tension of ordinary working currents, when a high-tension discharge occurs the particles under the influence of the discharge will generally be found to arrange themselves so closely as to make a conducting connection between the two points of the lightning-bridge. This can be experimentally demonstrated by allowing the secondary currents developed by a Ruhmkorff’s coil to spark through a loose mass of blacklead. The crucial test, however, is the behaviour of the bridge in practice. These lightning-bridges have been in use since January, 1866. At the present time there are upwards of one thousand doing duty in this country alone, and not a single case has occurred of a coil being fused when protected by them.

“ It is only right, however, to mention that three cases, but three cases only, have occurred where connection was made under the influence of electrical discharge between the two metallic points in the bridge. The protectors in which this occurred were amongst those first constructed, in which a larger proportion of conducting matter was employed than the inventor now adopts. The points also in those first constructed were approached to $\frac{1}{50}$th of an inch from one another. The author has no doubt, from an examination of the bridge afterwards, that under the influence of a high-tension discharge connection was made between the two metallic points by a bridge of conducting matter arranged closely together, and that if the instruments *had been shaken to loosen the powder*, all would have been put right. In one of these three cases—and it was the only one in which the author was supplied with the details—he ascertained that the protector was attached to a needle telegraph, having the ordinary magnetic needles made of tempered steel magnetized ; and on the removal of the bridge after the discharge, so completely had the electricity been carried away by the bridge that the magnetism of the magnetic needle was found not to have been affected."

IV

The principle of coherence seems to have again been lost sight of until rediscovered for the second time (in 1883) by Sir Oliver Lodge and J. W. Clark, when working together on the dust-free region seen over hot bodies when strongly illuminated in dusty air. They were investigating the dust-free spaces discovered by Tyndall, which are readily seen by placing a lighted spirit-lamp or a hot poker in the beam of an electric lamp. Tyndall thought the dust was calcined or burnt up, and that the air was thus freed from it, but the true explanation is connected with the bombarding effect of gas molecules as illustrated in the Crookes radiometer. The dust particles are beaten away from the hot body by a molecular bombardment, which manifests itself even at ordinary pressures on bodies of sufficiently small size, as indeed was also otherwise shown by Tait and Dewar and Osborne Reynolds in the course of remarkable theoretical and practical investigations.[1]

Before arriving at this explanation, however, Lodge and Clark

> " experimented to see if the phenomenon was caused by the air having become slightly electrified, perhaps by reason of its having streamed as an upward convection current over the surface of the warm solid, at which we were looking, in a thick smoky atmosphere, in the concentrated light of an electric arc. We therefore purposely electrified the rod, to see what that would do, and we found to our surprise, directly the electric machine was turned, that the smoky atmosphere almost instantaneously disappeared, and the box became quite clear." [2]

The experiment was demonstrated publicly for the first time at the Dublin Royal Society, and subsequently at the British Association at Montreal, in 1884,[3] where it was applied to the experimental clearing of rooms from dense smoke and fumes.

The principle was also studied by an Italian professor,

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[1] *Dimensional Properties of Matter*, *Phil. Trans.*, 1879.

[2] Lodge: *Signalling Through Space Without Wires*, p. 58.

[3] *Nature*, 24th April, 1884, and *Journal of the Royal Institution*, May, 1886.

Calzecchi-Onesti, and is dealt with in his little-known account of his researches. Onesti discovered that copper filings, heaped between two brass plates, were ordinarily non-conductors of electricity but that they became conductive when subjected to the discharge from an induction coil, when their resistance fell from millions to hundreds of ohms. Calzecchi-Onesti published his discoveries in *Il Nuovo Cimento* in 1884,[1] but, as has been the case with other wonderful wireless discoveries, his work attracted no attention until after the publication, six years later, of Branly's researches. Then the earlier discoveries of Varley and Onesti were remembered and it was seen that they had a considerable value.

V

In 1889, Lodge had incidentally observed again further cohesive action whilst working on the subject of protection of telegraphic instruments and cables from lightning.

> "When lightning itself strikes a guard," he said, "it has indeed often been found that the opposite sides of the protective air-gap are fused together. This, no doubt, may be partly due to a straightforward melting or welding by heat, but it is probably not solely that. Molten metals without a flux do not so readily weld. It is almost certainly due to a cohesive action also, the difference of potential between the molten terminals resulting in adhesion and amalgamation, a phenomenon also observed in the frequent locking of an electric arc formed between two metallic electrodes.
>
> "However this may be, certainly the phenomenon occurs on a small scale, for if the pair of knobs or points placed as a shunt to protect a galvanometer or other telegraphic instrument from lightning (or what is easier experimentally and essentially the same thing, from a Leyden jar discharge) be set too close together, the galvanometer will be found to be short-circuited after a spark, and the knobs will be found, both by mechanical and electrical tests, to be feebly united at a single point.[2] Not only, however, is the galvanometer short-circuited by the metallic junction so formed, but at the instant of the formation of the joint it experiences a very perceptible kick, indicating a momentary current, coincident no doubt with the electric discharge, but one from which it would have been protected had not the junction occurred. The galvanometer kick is clearly an effect due to the uniting metals, but it has not yet been fully elucidated. It seems to

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[1] Of which see p. 58. (See also *Journal, Institution of Electrical Engineers*, vol. xvi, p. 156.)

[2] *Modern Views*, p. 359.

[illegible]

> have been first observed by Mr. Stroh in his excellent researches on microphonic action, and it may possibly be thermo-electric, as Professor Hughes, who also observed it, thinks likely. It may be electro-chemical, or it may be connected with an effect observed later by FitzGerald in his galvanometer mode of detecting Hertzian waves, which he published at the Royal Institution in 1890.
>
> " The point of present interest is the cohesion that sets in between the knobs when the spark occurs. An extremely feeble spark was found sufficient to produce the effect, provided the surfaces were already almost infinitely close together, i.e., provided they were already in what would be called contact, with the merest imperceptible film of (probably) oxide separating them, just the kind of film that a chemical flux is useful in removing. The electrical stimulus appears to act as such a flux, and the adhesion of the two surfaces was demonstrated by an electric bell and single cell in circuit. Every time the spark occurred the bell rang, and continued ringing, until the table, or some part of the support of the knobs, was tapped so as to shake or jar them asunder again."[1]

In 1890–1 Professor Minchin,[2] working at Cooper's Hill with his sensitive photo-electric cells, found that his " impulsion cells " behaved abnormally when subjected to taps or other mechanical vibrations and lost their sensitiveness. Later he noticed that they regained it and responded to signals when Gregory was working a Hertz radiator in another part of the same laboratory.[3] " Many other detectors have been devised and used," says Lodge, " but this of Minchin's almost certainly depends on the cohesion principle, though its action seemed paradoxical then. Moreover he was able, by its aid, to signal without wires over a considerable number of yards, at that early date (1890 and 1891).[4]

VI

Branly, probably having had his attention drawn to the subject by reading of the work of Calzecchi-Onesti or Lodge and Clark, commenced a series of investigations into the variations of conductivity of a large number of conductors under different electrical influences, a subject that he erroneously, as we have seen, claimed had not previously been investigated. The results of his researches, which were of the greatest interest and importance, were given in a paper, published in 1891:[1] that a coat or varnish of fine copper dust, porphyrized copper, or other such substance, though a bad conductor under ordinary conditions, fell in resistance enormously whenever an electric spark occurred in its neighbourhood, in a somewhat similar manner to that in which the resistance of selenium falls on exposure to light. He measured the reduction in resistance caused in a number of different substances, including a quantity of metallic filings and conglomerates, or pastes made of filings in various viscous liquids, and in dry powders. He found that the resistance of these filings was reduced even when the spark from an induction coil was several yards distant.[2]

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[1] *Journal of the Institution of Electrical Engineers*, 1890, p. 352. See also remarks by Mr. Stroh in two microphone discussions, *Journal of the Institution of Electrical Engineers*, 1883 and 1887.

[2] Minchin had devised an instrument more sensitive to radiation even than Boys' radiomicrometer, in that it responded to the radiation of a star while the radiomicrometer did not.

[3] *Phil. Mag.*, March, 1891 ; also January, 1894, p. 223.

[4] Lodge : *Signalling Through Space Without Wires*, p. 64.

He pointed out that the enormous resistance offered by metal in a state of powder is well known; indeed, if we take a somewhat long column of very fine metallic powder, the passage of the current is completely stopped. The increase in the electrical conductivity of powdered conducting substances under pressure is also well known, and has had various practical applications.

> "Let us take a circuit," he said, "comprising a single cell, a galvanometer, and some powdered metal enclosed in an ebonite tube of 1 sq. cm. cross section and a few centimetres in length. Close the extremities of the tube with two cylindrical copper tubes pressing against the powdered metal and connected to the rest of the circuit. If the powder is sufficiently fine, even a very sensitive galvanometer does not show any evidence of a current passing. The resistance is of the order of millions of ohms, although the same metal melted or under pressure would only offer (the dimensions being the same) a resistance equal to a fraction of an ohm. There being, therefore, no current in the circuit, a Leyden jar is discharged at some little distance off, when the abrupt and permanent deflection of the galvanometer needle shows that an immediate and a permanent reduction of the resistance has been caused. The resistance of the metal is no longer to be measured in millions of ohms, but in hundreds. Its conductivity increases with the number and intensity of the sparks.

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[1] Published in *La Lumière Electrique*, May and June, 1891. See also *Electrician*, vol. xxvii, pp. 221, 448.

[2] *Comptes Rendus*, vols. cxi and cxii, and the *Electrician*, vol. xxvii, pp. 221 and 448.

"Some 20 or 30 cm. from a circuit comprising some metallic filings contained in an ebonite cup, let us place a hollow brass sphere, 15 to 20 cm. in diameter, insulated by a vertical glass support. The filings offer an enormous resistance and the galvanometer needle remains at zero. But if we bring an electrified stick of resin near the sphere, a little spark will pass between the stick and the sphere, and immediately the needle of the galvanometer is violently jerked and then remains permanently deflected. On some fresh filings being placed in the ebonite cup, the resistance of the circuit will again keep the needle at zero. If now the charged brass sphere is touched with the finger, there is a minute discharge and the galvanometer needle is again deflected. With a few accumulators the experiment can easily be made without a galvanometer. The circuit consists of the battery, some metallic powder, a platinum wire, and a mercury cup. The resistance of the powder is so high that the interruption of the circuit takes place without any sparking of the mercury cup. If now a Leyden jar is discharged in the neighbourhood of the circuit the powder is rendered conducting, the platinum wire immediately becomes red-hot, and a violent spark occurs on breaking the circuit.

"The influence of the spark decreases as the distance increases, but its influence is observable several metres away from the powder, even with a small Wimshurst machine. Repeating the spark increases the conductivity; in fact, with certain substances successive sparks produce successive jerks, and a gradually increasing and persistent deflection of the galvanometer needle."[1]

VII

Branly found that the substances in which the phenomenon of the sudden increase of conductivity is most easily observed are filings of iron, aluminium, copper, brass, antimony, tellurium, cadmium, zinc, bismuth, etc. He pointed out that the size of the grains and their nature are not the only elements to be considered, for grains of lead of the same size, but coming from different quarters, offer at the same temperature great differences in resistance (20,000 to 500,000 ohms). Extremely fine metallic powder, as a rule, offers almost perfect resistance to the passage of a current. But if we take a sufficiently short column and exert a sufficiently great pressure, a point is soon reached when the electrical influence will effect a sudden increase in the conductivity. Thus, a layer of copper reduced by hydrogen, which does not become conducting under the influence of the electric spark or otherwise, will become so on being submitted to a pressure of 7 lb. per square inch. Instead of using pressure, he employed as a conductor, in some experiments, a very fine coating of powdered copper spread on a sheet of unpolished glass or ebonite 7 cm. in length and 2 cm. in breadth. " A layer of this kind, polished with a burnisher, has a very variable resistance," he said, " and with a little care one can prepare sheets that are more or less sensitive to electrical action."

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[1] For full report of Branly's paper see *The Electrician*, 26th June and 21st August, 1891.

Branly pointed out that metal powders or metal filings are not the only sensitive substances, as powdered galena, which is slightly conductive under pressure, conducts much better after having been submitted to electrical influence. He found that powdered binoxide of manganese was not very sensitive, unless mixed with powdered antimony and compressed.

VIII

Not only did Branly confirm and extend the researches of earlier workers in this field, but he made the further important discovery that the conductivity imparted to metallic filings by an electrical discharge in the vicinity persists sometimes for a long period (twenty-four hours or more), but it is always possible to make it rapidly disappear, particularly by a shock.

The majority of substances tested showed an increase of resistance on being shaken, previous to being submitted to any special electrical influence, but after having been influenced the effect of shock is much more marked. The phenomenon was best seen with the metallic filings, but it could also be observed with metallized ebonite sheets with mixtures of liquid and metallic powders, mixtures of metallic filings and insulating substances (compressed or not compressed), and finally with solid bodies. He discovered that the conductivity of the substances is immediately destroyed by tapping the tube in which they are contained, and he thus discovered a vital operation, that which soon after was to form the foundation of Marconi's system.

" When the electric action has been of a powerful character," Branly wrote, " violent blows are necessary. I employed for the purpose of these shocks a hammer fixed on the table, the blows of which could be regulated. With some substances, when feebly electrified, the return seemed to be spontaneous, although it was slower than the return of the galvanometer needle to equilibrium. This restoration of the original resistance is attributable to surrounding trepidations, as it was only necessary to walk about the room at a distance of a few metres or to shake a distant wall. This spontaneous return to original resistance after weak electrical action was visible with a mixture of equal parts of fine selenium and tellurium powders. The restoration of resistance by shock was not observable so long as the electrical influence was at work. After having been submitted to powerful electric action, shock does not seem to entirely restore substances to their original state—in fact, the substances generally show greater sensitiveness to electric action."

IX

Very modestly does Branly speak of his work to-day.

" As for my coherer," he told the writer recently, " I suppose I did help the progress of radio-telegraphy. For years I studied the conductibility of isolated bodies, and at last, in this very building, I made my first discovery. I scarcely imagined at the time that similar results could be obtained at greater distances.

" In making my experiments I placed in the corner of the yard opposite my laboratory a spark coil, and in my laboratory a tube filled with soft-iron filings, closed at both ends by two conductor stoppers communicating by means of a cell and a bell. Although the circuit was closed the bell did not ring, but as soon as the current entered the spark coil the bell rang continuously. The principle of wireless telegraphy was thus found, for it was possible to collect the waves transmitted by the spark coil without using a metallic conductor. I noticed that this conductibility, once started, continued, and in order to make it cease I had to tap the tube slightly.

" Marconi profited by these experiments, and on achieving tangible results he sent me a testimonial of his admiration and thanks by a Marconigram from St. Margaret's, England, reading : ' Marconi sends Mr. Branly his respectful compliments across the Channel, this fine achievement being partly due to the remarkable researches of Mr. Branly.'

" My difficulties have always been tremendous. I have never been well off and so have always lacked appliances. That forced me to study medicine and earn a living as a doctor. Of course, it has helped me, and by making others well I know how to look after myself. I am never ill, and although I know monkey glands are good for some people, I do not think I will bother ! "

PLATE XIV

AUGUSTO RIGHI
(1850-1920)

EDOUARD BRANLY
(b. 1844)

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ALEXANDER STEPANOWITCH POPOFF
(b. 1859)

NIKOLA TESLA
(b. 1857)

X

The value of Branly's scientific work has been recognized and many honours have been awarded him. He was a prizeman of the Academy of Sciences in 1898, and at the Universal Exhibition of 1900 was awarded a Grand Prix. Later he became a Chevalier of the Legion of Honour with the following mention in the *Official Gazette*: "Discovered the principle of wireless telegraphy." In 1910 the Society for the Encouragement of National Industry awarded him their "Argenteuil" Prize, and since that year he has been an Associate Member of the Belgian Royal Academy. Further honours were bestowed upon him in 1921, when he was awarded the Nobel Physics Prize, and in 1925, when he received the order of Commander of the Legion of Honour.

It is doubtful whether Branly realized he was dealing with Hertzian waves when experimenting with his coherer. So short a time had elapsed between Hertz announcing his discovery of the electro-magnetic waves and Branly's invention, that it seems likely that the properties of the Hertzian waves were not fully recognized. It would seem that Branly was probably more concerned with demonstrating and investigating the principle of the alteration in the resistance of different metals when an electric spark occurred in the neighbourhood. He was, in fact, more interested in measuring the reduction in resistance caused in the various and numerous substances of his experiments than in the application of the discovery to larger and practical issues.

Nothing further transpired until 1892, when Dr. Dawson Turner described Branly's experiments at the British Association at Edinburgh. The following year Croft brought them to the notice of the London Physical Society, and Professor Minchin, realizing that the phenomenon was analogous to what he had been observing in his impulsion cells, read a paper before the same Society giving an account of his repetitions and modifications of Branly's experiments.[1] This paper came to the notice of Sir Oliver Lodge, who—as we have seen—had already done some work in the same direction, and he pointed out that Branly's discovery was another case of the electrical cohesion phenomenon already observed by several experimenters. He "at once proceeded to try the Branly tube of filings, and found it far superior in manageability" to the apparatus he had previously been using. Lecturing in London and in Oxford in 1894, he repeated all Hertz's experiments and demonstrated the efficiency of the Branly coherer.

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[1] See *Phil. Mag.*, January, 1894.

XI

In 1895 Popoff, a Russian physicist at the Torpedo School, Kronstadt, employed Branly's coherer in conjunction with a Morse printer. Connecting them to a lightning conductor, he caused distant lightning flashes to record themselves. Popoff's work is of such an interesting character that we must pause to consider it in further detail.

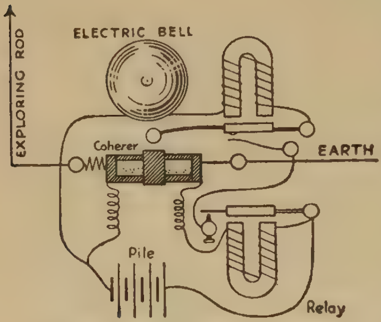

Fig. 22—Popoff's apparatus

Alexander Stepanowitch Popoff (*c*, Plate XIV) was born in 1859 at Bogosloosky Zawod, in the Ural district. His father was a priest and Alexander's scientific career commenced in 1877, when he entered the University of St. Petersburg. It was in 1895 that he conceived the idea of using the Hertzian waves and Branly's coherer to study atmospheric electricity. He used steel filings and introduced an electric "tapper" that automatically restored the metallic dust used in the coherer to a normal condition after the passage of an electric wave.

Popoff's apparatus consisted of a coherer, which, together with the electro-magnet of a relay, was linked in the circuit of a battery (Fig. 22). If the contents of the coherer, under the influence of the electro-magnetic waves, were rendered conductive, the electro-magnet drew down its armature. By that means the contact was closed, and the current conducted through the (until now) open circuit, which included the electro-magnet of an electric bell. This now drew its armature, and the striker hit the bell. At the same moment the circuit was interrupted, and the striker fell back into its original position, in doing which it shook the coherer. The apparatus, therefore, after announcing by the ringing of the bell the passing of the electric waves, was automatically restored to the condition to be again influenced by the etheric waves. The relay actuated another circuit (not shown in the diagram) which contained a Richard's register for setting down in graphic signs the electric perturbations of the atmosphere. It will be noticed that Popoff's arrangement is very similar to that subsequently adopted by Marconi, and the similarity becomes pronounced when we find him using a vertical aerial, known in those days as an " exploring rod ".

That Popoff was fully alive to the fact that greater issues were perhaps possible for his apparatus is shown by his remarks in a subsequent note (dated December, 1895) to a paper read (April, 1895) before the Physico-Chemical Society of St. Petersburg. In this note he said : " I entertain the hope that when my apparatus is perfected it will be applicable to the transmission of signals to a distance by means of rapid electric vibrations—as soon as a sufficiently powerful generator of these vibrations is discovered."

It has been publicly stated that Popoff followed his paper with a practical demonstration (7th May, 1895) before the Chemical Society of Russia, in the Laboratory of the University of St. Petersburg, and that on the occasion of this experiment the receiving station was located at a distance of 40 m. from the transmitter. As each signal, in the Morse code, was received, the President of the Society wrote the corresponding letter on the blackboard. A vivid word picture has been drawn of the intense enthusiasm of the audience of savants as these letters slowly spelled out the name " Heinrich Hertz ". Despite every endeavour to do so, it has been found impossible to verify this statement, however, and until further confirmation is forthcoming this claim—that an actual demonstration of the first practical system of wireless telegraphy was made in Russia—must be accepted with reserve.

Later in the same year (1895) Popoff discovered that reception was improved when a vertical conductor of several metres length was used. He arranged distant control apparatus by which an electric bell, included in the receiving circuit, was caused to ring when the transmitter was operated in different parts of the Naval College at Kronstadt.

Popoff seems to have concluded, from his 1895 experiments, that 40 m. would be the limit of range for wireless transmission until a more powerful generator was discovered. He seems thereafter to have reverted to his original field of investigation, for we find him carrying out further experiments to ascertain the nature of thunderstorm discharges and the conductivity of the atmosphere. He published his conclusions in the *Proceedings* of the Physical Society of Russia in the following year (1896) and a summary of his paper appeared in the *Journal de Physique* for November, 1897.

No more is heard of Popoff's system of wireless communication until after Marconi's success in England. Then, probably using a more sensitive detector, and using a Hertzian exciter of 30 cm. diameter, with a Siemens and Halske's relay, he succeeded (April, 1897), in transmitting signals over a distance of 1 km. By using a Bjerknes exciter of 90 cm. diameter he subsequently increased this distance to 1½ km., and finally to 5 km., which appears to have been the maximum distance over which he transmitted at any time. In all these transmissions he used vertical wires 18 m. in height.

Looking back at Popoff's work, we see that he certainly made some contribution to the science, but he was misled in looking for a more powerful generator, which, after all, could easily have been devised. What actually was wanted was a more sensitive detector than the form of Branly coherer he was using. As we shall shortly learn, this improvement was furnished by Marconi in his magnetic detector, which was the one thing lacking to make Popoff's system practical.

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CHAPTER XV

TESLA AND HIS EXPERIMENTS IN WIRELESS TRANSMISSION OF ENERGY

BEFORE passing on to consider the final phase of wireless communication, as represented by Marconi, mention must be made of one other pioneer, Tesla, who worked perhaps in a less spectacular manner than those who gained a certain amount of publicity. Tesla's early efforts are often overlooked, and it is only fair that his name should be mentioned so that he may share in the credit due to the early investigators. Tesla experimented early in the problem of transmitting electrical energy without wires. In February, 1893, he advanced a plan of wireless transmission and expressed his conviction in a lecture at the Franklin Institute, Philadelphia, that " it certainly is possible to produce some electrical disturbance sufficiently powerful to be perceptible by suitable instruments at any point of the earth's surface ".

Nikola Tesla (*d*, Plate XIV), born in 1857 at Smiljan, Lika, on the borderland of Austria-Hungary, belonged to a race that has maintained against Turkey and all comers an unceasing struggle for freedom. The son of a clergyman in the Greek Church, he evidently inherits his inventiveness from his maternal grandfather. His mother was of an inventive nature, too, inventing and constructing such mechanical appliances as looms and churns and other machinery required in a rural community.

Nikola was sent to an elementary school for a year and then to the Lower Realschule, Gospich, Lika, for four years. He spent the next three years at the Higher Realschule, Carlstadt, Croatia, where he graduated in 1873, and it was whilst here that he saw a steam locomotive for the first time. He devoted himself to experimenting in electricity and magnetism.

His father wished him to maintain the family tradition and enter the Church, but his inherited genius for inventions and mechanics was too strong. He was allowed to enter the Polytechnic at Gratz to finish his studies, with the object of becoming a professor of mathematics and physics. One of the machines at the Polytechnic was a Gramme dynamo, used as a motor, and despite his instructor's theoretical demonstration of the fact that it was impossible to operate a dynamo without commutator or brushes, Tesla was unconvinced that such accessories were necessary or desirable. With quick intuition he had already seen that they could be dispensed with, and from that time he may be said to have commenced the work that resulted ultimately in his discovery of the rotating-field motor.

In the second year of his course at Gratz, Tesla relinquished the idea of becoming a teacher, and instead took an engineering course. When his studies were ended he returned home, and four years later went to Prague, where he studied philosophy at the University, going on to Budapest to study languages, with the object of qualifying himself further for the engineering profession. Here, in 1881, for a short time, he served as an assistant in the Government Telegraph Engineering Department, in which capacity he became associated with Puskas and other pioneers of the telephone in Hungary. Tesla brought out a number of telephonic inventions, including his telephone repeater, but finding that his opportunities of benefiting by them were too limited, he decided to move to a wider field of action. With this purpose in view he went to Paris, where he secured employment as an electrical engineer with one of the large companies in the new industry of electric lighting.

It was during this period, and as early as 1882, that he made serious and continued efforts to embody the rotating-field principle in a practical manner in dynamos. He was very enthusiastic about it, believing that the invention would create an entirely new departure in electricity. He could think of nothing else, and but for the representations of a few friends in commercial circles, who urged him to form a company to exploit the invention, Tesla—having but little worldly experience—would have at once published his ideas. He had met many Americans in France and had learned from them the desirability of turning every new idea in electricity to practical use. He learned also of the ready encouragement given in the United States to any inventor who could produce new and valuable results, and with characteristic impetuosity he abandoned all his prospects in Europe, and in 1884 set his face westward to try his fortune in America.

Arrived in the United States, Tesla " took off his coat " the day he arrived, in the Edison Works, which had been a goal of his ambition, and one can readily imagine the benefit and stimulus derived from his association with Edison. It was impossible, however, that, with his own ideas to carry out and his own inventions to develop, Tesla could long remain here. As his work was now commencing to attract attention, he left Edison to join a company intended to make and sell an arc-lighting system based on some of his inventions. Through unceasing diligence he brought the system to perfection and saw it placed on the market, but all through this period his old idea, of the rotating-field principle for alternating-current work and the application of it in motors, occupied first place in his time and thoughts.

Strong as his convictions on the subject then were, it is a fact that he stood very much alone, for the alternating current had no recognized place at that time. Few electrical engineers had ever used it, and the majority were entirely unfamiliar with its value, or even its essential features. Even Tesla himself did not, until after protracted effort and numerous experiments, learn how to construct an efficient alternating-current apparatus. But that he had accomplished his purpose was shown by the tests of Professor Anthony, made in the winter of 1887–8, when Tesla motors gave an efficiency equal to that of direct-current motors. Nothing now stood in the way of the commercial development and introduction of such motors, except that they had to be constructed with a view to operating on the circuits then existing, which in America were all of high voltage. The first full publication of his work in this direction—outside his patents—was a paper read before the American Institute of Electrical Engineers in New York (May, 1888), when he exhibited motors that had been in operation long previous, and with which he proved that brushes and commutators could be dispensed with.

Having noted for years the many advantages obtainable with alternating currents, Tesla was naturally led to experiment at higher potentials and higher frequencies than were common or even approved of. Ever pressing forward to determine in even the slightest degree the outlines of the unknown, he was rewarded very quickly in this field with results of the most surprising nature. The experiments were repeated before the American Institute of Electrical Engineers in May, 1891, in a lecture that marked a distinct departure in electrical theory and practice.

Tesla's work ranged far beyond the vast possibilities of polyphase currents and high-frequency lighting, and he has a great many other inventions to his credit, including his system of arc lighting (1886). Tesla motor and system of alternating-current power transmission (1888). System of electrical conversion and distribution by oscillating discharges (1889). Generators of high-frequency currents (1890). Tesla coil or transformer (1891). A system of wireless telegraphy (1893). Mechanical oscillators and generators (1894–5). Researches and discoveries in radiations and emanations (1896–8). High-potential magnifying transmitter (1897).

Tesla was engaged, between 1897 and 1905, in developing his system of transmission of power without wires, and since 1903 he has been occupied in designing and developing plant for transmission of power without wires to be erected at Niagara. He has also been at work on appliances to make possible efficient electric light with lamps without filaments. His discovery of the action of air or gaseous matter, when subjected to rapidly alternating electrostatic stresses, is the basis of the modern methods of insulating wires carrying currents of exceedingly high tension.

II

Tesla's early work in connection with the transmission of electrical energy without wires was an attempt to solve not only the problem of telegraphy but also that of transmitting energy for industrial purposes. He described his plan in detail thus:

"Assume that a source of alternating current, s (Fig. 23), be connected with one of its terminals to earth (convenient to the water mains), and with the other to a body of a large surface, P. When the electric oscillation is set up, there will be a movement of electricity in and out of P, and alternating currents will pass through the earth, converging to or diverging from the point C, where the ground connection is made. In this manner neighbouring points on the earth's surface within a certain radius will be disturbed. But the disturbance will diminish with the distance, and the distance at which the effect will still be perceptible will depend on the quantity of electricity set in motion. Since the body P is insulated, in order to displace a considerable quantity the potential of the source must be excessive, since there would be limitations as to the surface of P. The conditions might be adjusted so that the generator, or source, S, will set up the same electrical movement as though its circuit were closed.

"Thus it is certainly practicable, by means of proper machinery, to impress an electric vibration, at least a certain low period, upon the earth. Theoretically it should not require a great amount of energy to produce a disturbance perceptible at great distance, or even all over the surface of the globe. Now, it is quite certain that at any point within a certain radius of the source, S, a properly adjusted self-induction and capacity device can be set in action by resonance. Not only can this be done, but another source, S^1 (Fig. 23), similar to S, or any number of such sources, may be set to work in synchronism with the latter, and the vibration thus intensified and spread over a large area; or a flow of electricity produced to or from the source S^1, if the same be of opposite phase to the source S. Proper apparatus must first be produced, by means of which the problem can be attacked, and I have devoted much thought to this subject."

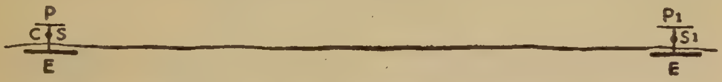

FIG. 23—TESLA'S PLAN FOR WIRELESS TRANSMISSION OF POWER

Tesla explained his plan in lectures, delivered February and March, 1893, before the Franklin Institute in Philadelphia and the National Electric Light Association in St. Louis. He showed, on each occasion, several interesting experiments, including systems that required only one wire instead of two usually employed. He also lectured (1893) before the Institution of Electrical Engineers in London on *Experiments with Alternate Currents of High Potential and High Frequency* and described methods of generating the currents required for wireless telegraphy.[1]

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[1] *Forty Years of Electrical Progress* (1916).

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III

Continuing his researches, he developed (in 1898) apparatus of considerable power by which he obtained pressures of four million volts, discharging across 16 ft.[1]

During 1925 we heard a good deal about a so-called " death-ray ", which Grindell-Matthews claimed to have " invented ". The technical details of this experiment are his own particular secret, but it is not impossible that he relied on the principle of the ionization of a beam of light, which thus becomes a conductor of electricity. Whether the " death-ray " is effective at any distance, outside a laboratory, remains as yet unproved. It is a known fact, however, that in certain circumstances electro-magnetic waves are able to cause considerable damage to the magnetos of aeroplanes, motor-cars, and the like, and in this connection Tesla's work in 1898 gives us an excellent illustration.

In that year the Colorado Electric Light Company, U.S.A., were alarmed to find that the armatures of their big dynamos were suddenly burnt out, or fused, for no apparent reason. The engineers could find no technical causes that would account for the damage. New armatures were installed at considerable cost, but scarcely had the work been completed before a similar disaster again overtook them, and the armatures were burnt out a second time, this time beyond repair.

To cut a long story short, the trouble was traced to the experiments that Tesla was conducting in his laboratory, *five miles away from the Colorado Company's works!* His experiments were so far advanced, and conducted on such a gigantic scale, that he was able to radiate sufficient energy to effectually burn out the armatures of the Colorado Company's dynamos at a distance of five miles. This was not all, however, for it was found that the energy generated by Tesla's apparatus adversely affected dynamos up to distances of thirteen miles, and Tesla had prompt orders to modify his experiments.

By these experiments Tesla was endeavouring to ascertain the laws of propagation of electrical waves through the earth. He used a 300-kw. generator (equal to 400 h.p.), a step-up transformer, and an inductance coil of 50 ft. diameter. He also used a huge spark-gap, between the knobs of which flashed a spark sometimes 100 ft. in length and of power at that time unheard of.

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[1] See *Electrical Review*, New York, 26th October, 1898.

Thus in 1898 Tesla found that by electro-magnetic induction, or the propagation of very powerful electro-magnetic waves, it is possible to set up high-frequency oscillations in the armature windings of a dynamo and cause these windings to fuse and burn out. The principle was really induction on a colossal scale.[1]

IV

Tesla was of opinion that with his high-power oscillators there is no limit to the intensity of the effects and magnitude of the forces produced, and that even interplanetary space might be bridged by the terrific commotions set up in the ether.

> " However extraordinary the results shown may appear," he said, " they are but trifling compared with those that are attainable by apparatus designed on these same principles. I have produced electrical discharges, the actual path of which, from end to end, was probably more than one hundred feet in length, and it would not be difficult to reach lengths one hundred times as great. I have produced electrical movements occurring at the rate of approximately one hundred thousand horse-power, but rates of one, five, or ten million horse-power are easily practicable. In these experiments effects were developed incomparably greater than any ever produced by human agencies, and yet these results are but an embryo of what is to be.
>
> " That communication without wires to any point of the globe is practicable with such apparatus would need no demonstration, but through a discovery that I made I obtained absolute certitude. Popularly explained, it is exactly this : When we raise the voice and hear an echo in reply, we know that the sound of the voice must have reached a distant wall or boundary, and must have been reflected from the same. Exactly as the sound, so an electrical wave is reflected ; and the same evidence which is afforded by an echo is offered by an electrical phenomenon known as a ' stationary ' wave—that is, a wave with fixed nodal and ventral regions. Instead of sending sound vibrations toward a distant wall, I have sent electrical vibrations toward the remote boundaries of the earth, and instead of the wall the earth has replied. In place of an echo I have obtained a stationary electrical wave—a wave reflected from afar.
>
> " Stationary waves in the earth mean something more than mere telegraphy without wires to any distance. They will enable us to

---

[1] His experiments were described and illustrated in the *Century Magazine* for June, 1900.

> attain the many important specific results impossible otherwise. For instance, by their use we may produce at will, from a sending-station, an electrical effect in any particular region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed; or we may send over the earth a wave of electricity travelling at any rate we desire, from the pace of a turtle up to lightning speed." [1]

From a comparatively small oscillator a "spark" over 23 ft. in length was obtained. A current of approximately 800 amperes was passing through the air, and was accompanied by "a roar like Niagara", which "can be heard several miles" distant.

V

For this system Tesla was granted two patents (Nos. 645576 and 649621) on 20th March and 15th May, 1900, the original applications having been filed on 2nd September, 1897. From the specifications of these patents it is clear that Tesla's system is radically different from that of Hertz, both in the methods and apparatus used. Tesla does not rely on using the radiated energy, but a current is led to earth and to an elevated terminal, and the energy is transmitted by conduction.

> "It is to be noted", he points out, "that the phenomenon here involved in the transmission of electrical energy is one of true conduction, and is not to be confounded with the phenomena of electrical radiation which have heretofore been observed, and which, from the very nature and mode of propagation, would render practically impossible the transmission of any appreciable amount of energy to such distances as are of practical importance.
>
> "The method herein described of transmitting electrical energy through the natural media consists in producing at a generating station a very high electrical pressure. This causes a propagation or flow of electrical energy, by conduction, through the earth and the air strata, and the electrical energy so propagated or caused to flow is collected or received at a distant point. The combination includes a transmitting coil or conductor connected to ground and to an elevated terminal respectively, and means for producing electrical currents or oscillations in the same, of a receiving coil or conductor similarly connected to ground and to an elevated terminal, the said coil or coils having a length equal to one-quarter of the wave-length of the disturbance propagated, as set forth.
>
> "The transmitting apparatus was in this case one of my electrical

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[1] *Century Magazine*, June, 1900.

oscillators, which are transformers of a special type, now well known and characterized by the passage of oscillatory discharges of a condenser through the primary. The source G (Fig. 24), forming one of the elements of the transmitter, was a condenser of a capacity of about four one-hundredths of a microfarad, and was charged from a generator of alternating currents of 50,000 volts pressure, and discharged by means of a mechanically operated break 5,000 times per second through the primary C. The latter consisted of a single turn of stout, stranded cable of inappreciable resistance and of an inductance of about 8,000 cm., the diameter of the loop being very nearly 244 cm. The total inductance of the primary circuit was approximately 10,000 cm., so that the primary circuit vibrated generally according to adjustment from 230,000 to 250,000 times per second. The high-tension coil A in the form of a flat spiral was composed of fifty turns of heavily insulated cable No. 8 wound in one single layer, the turns beginning close to the primary loop and ending near its centre. The outer end of the secondary or high-tension coil A was connected to the ground.

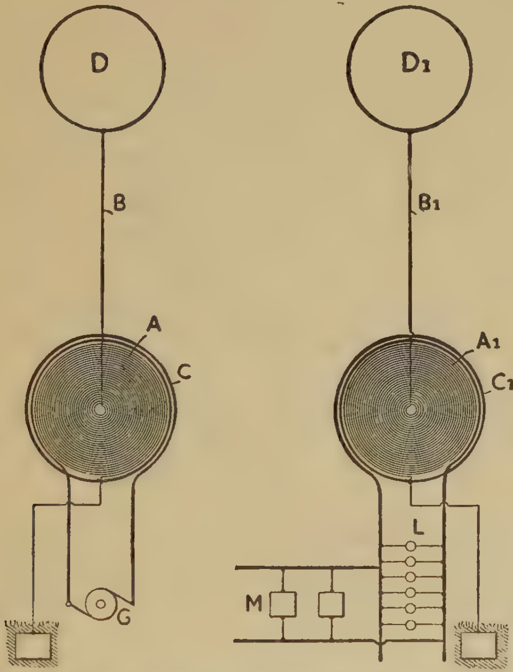

Fig. 24—Tesla's transmitting apparatus

"The primary and secondary circuits in the transmitting apparatus being carefully synchronized, an electromotive force of from 2,000,000 to 4,000,000 volts and more was obtainable at the terminals of the secondary coil A."

VI

Tesla's apparatus seemed to be capable of peculiar actions. For example, he tells us that

> "a conductor or terminal, to which impulses such as those here considered are supplied, but which is otherwise insulated in space and is remote from any conducting bodies, is surrounded by a luminous flame-like brush or discharge, often covering many hundreds or even as much as several thousands of square feet of surface. This striking phenomenon clearly attests the high degree of conductivity that the atmosphere attains under the influence of the immense electrical stresses to which it is subjected. This influence is, however, not confined to that portion of the atmosphere discernible by the eye as luminous, and which, as has been the case in some instances actually observed, may fill the space within a spherical or cylindrical envelope of a diameter of 60 ft. or more. It reaches out to far remote regions, the insulating qualities of the air being, as I have ascertained, still sensibly impaired at a distance many hundred times that through which the luminous discharge projects from the terminal, and in all probability much farther".

It was the conductivity imparted to the air by these currents that Tesla proposed to utilize for the wireless transmission of power for industrial purposes.

> "From my experiments and observations", he says, "I conclude that with electromotive impulses not greatly exceeding 15,000,000 or 20,000,000 volts, the energy of many thousands of horse-power may be transmitted over vast distances, measured by many hundreds and even thousands of miles, with terminals not more than 30,000 to 35,000 ft. above the level of the sea. Even this comparatively small elevation will be required chiefly for reasons of economy, and if desired it may be considerably reduced. By such means as have been described, practically any potential that is desired may be obtained, and the currents through the air strata may be rendered very small, whereby the loss in the transmission may be reduced. It will be understood that the transmitting as well as the receiving coils, transformers, or other apparatus may be in some cases movable—as, for example, when they are carried by vessels floating in the air or by ships at sea."

In other words, Tesla's idea was that if a captive balloon were put at seven miles elevation over Niagara Falls, and another balloon at the same height in France, energy from a dynamo at the former station might, without undue loss in transmission, be made to set electric motors in motion upon French territory, or to supply the power to illuminate electric lamps.

VII

On the 1st July, 1898, Tesla filed an application for another patent (No. 613809) in the specification of which he claimed his plan to be :

> " The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances conveyed to the vessel by the natural media. This actuates suitable apparatus on the vessel and effects the control of the propelling engine, the steering and other mechanism by the operation of the said mechanism as set forth."

A number of methods of producing these waves was then described, the most effective being apparently that of " passing through the conducting path currents of a specially designed high-frequency alternator, or better still, those of a strongly charged condenser ". The circuit was to be adjusted to the moving body " so as to be in exact synchronism with the primary disturbances ". This arrangement would enable " this influence to be utilized at great distances ".

Tesla pointed out that there were many useful purposes to which this invention could be applied. Its " greatest value will result from its effect upon warfare and armaments, for by reason of its certain and unlimited destructiveness it will tend to bring about and maintain perfect peace among nations ".

Tesla's system of electrical conversion by means of condenser discharges, in which the " Tesla coil " played an important part, was described in his American Patent of 3rd November, 1891 (No. 462418), application for which was filed on 4th February of the same year. In his specification Tesla says :

> " I employ a generator, preferably of very high tension, and capable of yielding either direct or alternating currents. This generator I connect up with a condenser or conductor of some capacity, and discharge the accumulated electrical energy disruptively through an air-space or otherwise into a working circuit containing translating devices

and, when required, condensers. These discharges may be of the same direction or alternating and intermittent, succeeding each other more or less rapidly or oscillating to and fro with extreme rapidity. In the working circuit, by reason of the condenser action, the current impulses or discharges of high tension and small volume are converted into currents of lower tension and greater volume. The production and application of a current of such rapid oscillations or alternations (the number may be many millions per second) secures, among others, the following exceptional advantages: First, the capacity of the condensers for a given output is much diminished; second, the efficiency of the condensers is increased and the tendency to become heated reduced; and, third, the range of conversion is enlarged.

"I have thus succeeded in producing a system or method of conversion radically different from what has been done heretofore—first, with respect to the number of impulses, alternations, or oscillations of current per unit of time, and, second, with respect to the manner in which the impulses are obtained. To express this result, I define the working current as one of an excessively small period or of an excessively large number of impulses or alternations or oscillations per unit of time. By this I mean not a thousand or even twenty or thirty thousand per second, but many times that number, and one which is made intermittent, alternating, or oscillating of itself without the employment of mechanical devices."

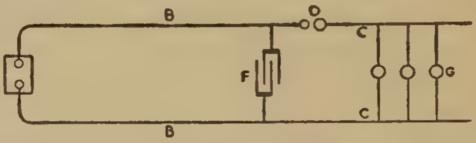

Fig. 25—Conversion by condenser discharges

The diagram (Fig. 25) accompanying the specification is referred to as follows:

"A represents a generator of high tension, B B the conductors which lead out from the same. To these conductors are connected the conductors C of a working circuit containing translating devices, such as incandescent lamps or motors G. In one or both conductors B is a break D, the two ends being separated by an air-space or a film of insulation, through which a disruptive discharge takes place. F is a condenser, the plates of which are connected to the generating circuit.

"The discharges will follow each other more rapidly the more nearly the rate of supply from the generator equals the rate at which the circuit including the generator is capable of taking up and getting rid of the energy. Since the resistance and self-induction of the working circuit C and the rapidity of the successive discharges may be varied at will, the current strengths in the working and in the generating circuit may bear to one another any desired relation."

VIII

The so-called "Tesla Coil" was the subject of a patent (No. 454622) applied for on 5th April, 1891, and granted on 23rd June in the same year. In his specification of this invention Tesla says:

"To produce a current of very high frequency and very high potential, certain well-known devices may be employed. For instance, as the primary source of current or electrical energy, a continuous-current generator may be used, the circuit of which may be interrupted with extreme rapidity by mechanical devices. Or a magnèto-electric machine, specially constructed to yield alternating currents of very small period, may be used. In either case, should the potential be too low, an induction coil may be employed to raise it. Or, finally, in order to overcome the mechanical difficulties, which in such cases become practically insuperable before the best results are reached, the principle of the disruptive discharge may be utilized.

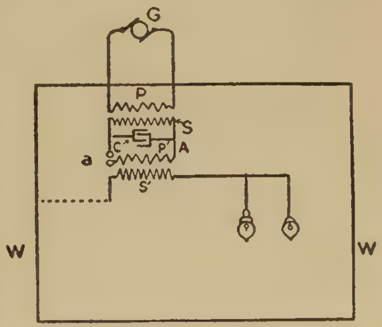

FIG. 26—TESLA'S COIL

"By means of this latter plan I produce a much greater rate of change in the current than by the other means suggested, and in illustration of my invention I shall confine the description of the means or apparatus for producing the current to this plan, although I would not be understood as limiting myself to its use. The current of high frequency, therefore, that is necessary to the successful working of my invention, I produce by the disruptive discharge of the accumulated energy of a condenser, maintained by charging the said condenser from a suitable source and discharging it into or through a circuit under proper relations of self-induction, capacity, resistance, and period in well-understood ways.

"Such a discharge is known to be, under proper conditions, intermittent or oscillating in character, and in this way a current varying in strength at an enormously rapid rate may be produced. Having produced in the above manner a current of excessive frequency, I obtain from it by means of an induction coil enormously high potentials. That is to say, in the circuit through which, or into which, the disruptive discharge of the condenser takes place I include the primary of a suitable induction coil. By a secondary coil of much longer and finer wire I convert to currents of extremely high potential."

The drawing (Fig. 26) attached to the specification is described thus:

> "G is the primary source of current or electrical energy. I have explained above how various forms of generator might be used for this purpose. In the present illustration I assume that G is an alternating-current generator of comparatively low electromotive force. Under such circumstances I raise the potential of the current by means of an induction coil having a primary P and a secondary S. Then by the current developed in this secondary I charge a condenser C, and this condenser I discharge through or into a circuit A, having an air-gap *a*, or, in general, means for maintaining a disruptive discharge. By the means above described a current of enormous frequency is produced. My object is next to convert this into a working circuit of very high potential, for which purpose I connect up in the circuit A the primary P of an induction coil having a long fine wire secondary S. The current in the primary P develops in the secondary S a current or electrical effect of corresponding frequency, but of enormous difference of potential."

IX

Numerous modifications of these principles were made and patented by Tesla, including a series of tuned circuits of high frequency that excited one another and which were a feature of the later patents. In his specification of the patent (No. 568178) granted 22nd September, 1896, for his system of Concatenated Tuned Circuits, Tesla says:

> "It is well known that every electric circuit, provided its ohmic resistance does not exceed certain definite limits, has a period of vibration of its own analogous to the period of vibration of a weighted spring. In order to alternately charge a given circuit of this character by periodic impulses impressed upon it, and to discharge it most effectively, the frequency of the impressed impulses should bear a definite relation to the frequency of vibration possessed by the circuit itself. Moreover, for like reasons, the period or vibration of the discharge-circuit should bear a similar relation to the impressed impulses or the period of the charging-circuit. When the conditions are such that the general law of harmonic vibrations is followed, the circuits are said to be in resonance or in electro-magnetic synchronism, and this condition I have found in my system to be highly advantageous. Hence, in practice, I adjust the electrical constants of the circuits so that in normal operation this condition of resonance is approximately attained. Any departure from this condition will result in a decreased output, and this fact I take advantage of in regulating such output by varying the frequencies of the impulses or vibrations in the several circuits.
>
> "Inasmuch as the period of any given circuit depends upon the relations of its resistance, self-induction, and capacity, a variation of

any one or more of these may result in a variation in its period. There are, therefore, various ways in which the frequencies of vibration of the several circuits in the system referred to may be varied, but the most practicable and efficient ways of accomplishing the desired result are the following: (*a*) varying the rate of the impressed impulses of current, or those directed from the source of supply into the charging-circuit, as by varying the speed of the commutator or other circuit-controller; (*b*) varying the self-induction of the charging-circuit; (*c*) varying the self-induction or capacity of the discharge-circuit."

X

An interesting discovery was the fact that the intensity of electrical oscillations is increased when the transmitting apparatus is cooled. "When a circuit adapted to vibrate freely is maintained at a low temperature," Tesla claimed, "the oscillations excited in the same are to an extraordinary degree magnified and prolonged."

The cooling agent may be any freezing mixture—liquid air, for instance—and valuable results, "heretofore wholly impracticable", are obtained.

Tesla applied this refrigerant to both transmitting and receiving coils and fully described the invention in his specification (filed 21st March, 1900) for his patent (No. 685012) granted 22nd October, 1901.

CHAPTER XVI

MARCONI REALIZES THE DREAM OF A CENTURY

LOOKING back to the closing years of the nineteenth century, we see clearly how the work of the pioneers of wireless was gradually leading to a grand climax. Clerk-Maxwell and Hertz had applied the match and the scientific world had taken up the torch. In Italy, Onesti and Righi; in France, Branly; in England, Lodge; in America, Tesla; in Russia, Popoff—all were devoting thought to the subject and contributing to the common cause in endeavouring to find a solution to the problem. Progress had been slow in the past, but soon the great labours of the earlier investigators were to bear fruit, and wireless telegraphy—the dream of the preceding century—was to become an accomplished fact. As all the world knows, the first to apply the latent possibilities of Hertz's discoveries in such a manner that they became a commercial success was Marconi.

Guglielmo Marconi (*a*, Plate XV) was born at Bologna, Italy, on 25th April, 1874. His father was a wealthy landed proprietor of Italy and his mother a member of an influential and well-known family of Dublin.

The early part of Marconi's life was without any remarkable incidents. He attended school and pursued the hobbies in which boys delight. There was nothing to show that he would become a great inventor, and at 19 years of age he is described as being a quiet grown-up boy, who talked little but thought much. He was shy and retiring and of a studious disposition, but underlying all was a quiet determination that had much to do with the great results accomplished at so early an age.

Educated at Bologna, Florence, and Leghorn, he had advantages that probably had a considerable influence in shaping his career. From early boyhood he showed a particular interest in electricity. Later, he was fortunate in being able to devote a good deal of time to experimenting, for a private income made it unnecessary to spend many years in a struggle for bare existence, so often the lot of scientists and inventors.

When Hertz commenced his famous experiments in 1886, Marconi was twelve years of age. Reading of the results of these experiments first suggested to Marconi the possibility of transmitting messages from one place to another without wires.

> " From my youth," Marconi has said,[1] " I would almost say from my boyhood, the experimental discovery of electric waves made by Hertz in confirmation of the mathematical hypothesis of Maxwell regarding the electro-magnetic theory of light, and the brilliant pursuit of such researches made by our great Bolognese physicist, Augusto Righi, . . . had fascinated my mind. I soon had the idea, I might almost say the intuition, that these waves might, in a not distant future, furnish mankind with a new and powerful means of communication utilizable not only across continents and seas, but also on board ships, bringing with it a vast diminution of the dangers of navigation and the abolition of the isolation of those crossing the sea. . . ."

At this time Augusto Righi was intensely interested in the Hertzian waves and was carrying on numerous experiments with them. There is no doubt that Righi's work had a marked influence on young Marconi, and caused him to turn his attention to the Hertzian waves. Even at this early age he repeated all the published experiments. His practical mind was quick to grasp the commercial possibilities of the discovery, but he could not believe that he was alone in this. The discoveries of the pioneers—the resonator, the aerials, the coherer, and the tapper—were ready to his hand, but they were equally at the disposal of men older than he and with a better scientific training. He thought every other scientist in the world would be studying the problem and would have come to the same conclusion as himself.

" I was deeply impressed," he has said, " owing to my experiments, with the value of the etheric waves. . . . I could scarcely conceive it possible that their application to useful

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[1] In his speech at Archiginnasio di Bologna when (in 1926) he revisited the scenes of his youth on the occasion of the 30th anniversary of the granting of his first patent. (See *The Wireless World*, 13th October, 1926.)

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purposes could have escaped the notice of eminent scientists." In this he resembled the great Frenchman, Jacquard, who feared to claim the reward for his loom because he believed that so many others would already have devised a similar machine.

Marconi therefore watched for some announcement of the practical application of the Hertzian waves. He searched the technical papers and reviews for a twelvemonth, but nothing of interest appeared. Astonished, he set to work on further experiments to improve his laboratory apparatus, which, at that time, was capable only of transmitting from one side of a table to another.

II

His experiments commenced in 1895 and were carried out at his father's country house, the Villa Griffone, at Pontecchio. In the garden Marconi erected a short pole at one side and connected the transmitting apparatus to it by insulated wire. At the other side of the garden a second pole was erected connected with the receiving apparatus. We may well believe that the young Italian did not for one moment dream of the vast developments, so near at hand, that were to arise from these early experiments. He could not have visualized the great transmitting stations at Glace Bay; at St. Assise; at Rugby; nor the great chain of wireless stations that now encircle the earth. He could not have conceived of the many applications of his invention that have since become possible—the " S O S " call of a stricken ship in mid-ocean; the communication with aeroplanes and airships in flight; and the numerous other developments. Little did he dream that his experiments were to result in evolving wireless telephony, so that grand opera played at Covent Garden may be heard in mid-Atlantic or even in New York. He could never have imagined the broadcasting that enables millions in all parts of the world to listen nightly to music and speech, nor could he have supposed that his pioneer experiments in directional working would later develop into the modern Beam System.[1]

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[1] Marconi used reflectors and directional working in Italy in his earliest experiments. They are extensively mentioned in his paper *Wireless Telegraphy*, read before the Institution of Electrical Engineers, 2nd March, 1899

His first experiments resulted in his being able to signal across the garden, but as he constantly improved his apparatus, the distance was increased until, in 1896, he succeeded in transmitting over two miles. Then he packed up and came to England and applied (2nd June, 1896) for provisional protection for his invention.[1] During the following month he obtained an introduction to Sir William Preece, Chief Engineer of the Post Office Telegraphs, who (as we have already seen) had himself carried out many experiments in wireless. In his official capacity Sir William eagerly took up the new system and greatly aided Marconi in its development.

III

In his system Marconi embodied the inventions of several pioneers, and by improving them in detail and adapting them individually to his requirements, he was able to bring them together so that collectively they formed a practical working system.

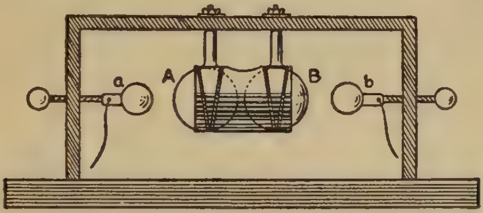

FIG. 27—MARCONI'S SPARK-GAP

A B. Solid brass spheres. *a b.* Small spheres.

His " wave-exciter " (Fig. 27) was practically identical with Righi's " three-spark exciter ", in which waves are propagated from the discharge that takes place between two or more brass balls or spheres by a short spark springing across through an insulating fluid. The spheres are charged by sparks that leap between them and two outer spheres, connected with a Ruhmkorff induction coil. In the primary circuit of this coil was a galvanic battery of a few cells and an interrupter, and a Morse key to form the Morse signals (Fig. 28). The receiver included a coherer similar to, but considerably more sensitive than, the original filings-tube of Calzecchi-Onesti, as developed by Branly and Lodge. The metallic filings were returned to their normal state, after cohesion, by the hammer of an electric bell and the local circuit was closed by a relay, both of which were similar in principle to those used by Popoff, but again improved in detail.

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[1] B. Patent No. 12039/96, U.S. Patent No. 586193, and reissue No. 11913.

In combining these ideas of earlier workers Marconi showed himself to be possessed of far-seeing initiative. He alone was sufficiently alert and practical to bring into operation a concrete scheme, whereas other scientists, who might have forestalled him but did not, continued to engage in laboratory research. Of his achievement Augusto Righi said, " Marconi carried into the domain of practical reality that which had only floated indistinctly before the minds of others, or had served them for modest experiments ". " They all knew the egg," said Sir William Preece, " but Marconi showed them how to make it stand on end." [1]

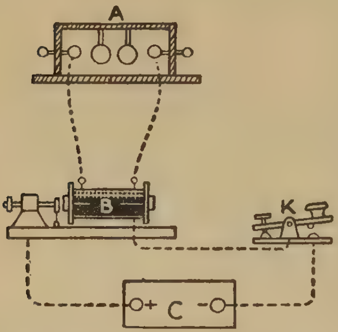

FIG. 28—CIRCUIT USED BY MARCONI IN EARLY EXPERIMENTS

A. Modified Righi exciter.
B. Ruhmkorff coil.
C. Battery.
K. Morse key.

There is another aspect of looking at the matter, which was so well expressed at the time by Sir Oliver Lodge that we cannot do better than quote his words :

> " An enthusiast in Italy," he wrote, " having learnt from Professor Righi about the production and transmission of Hertz waves across space, and their detection by the cohesion which they caused in a group of metallic filings, and being gifted, doubtless, with a sense of humour as well as with considerable energy and some spare time, proceeded to devise a suitable form of coherer, to put it inside a sealed

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[1] In upholding the validity of Marconi's original Patent, Judge W. K. Townsend in the United States Court Circular (11th April, 1905) held that " it would seem to be a sufficient answer to the attempts to belittle Marconi's great invention that, with the whole scientific world awakened by the disclosures of Hertz in 1887 to the new and undeveloped possibilities of electric waves, nine years elapsed without a single practical or commercially successful result. . . . Marconi was the first to describe and the first to achieve the transmission of definite intelligible signals by means of the Hertzian waves."

box and to bring it to England as a secret device adapted to electric signalling at a distance without wires. Being influentially introduced to the Chief Engineer of the Government Telegraphs, who, presumably, was too busy to remember what had recently been done in the Hertz-wave direction, the box was announced as containing 'a new plan' which had been 'brought to England'. Lectures were given on it at both the Royal Institution and the Royal Society, and trials were made by the experienced official staff with their usual skill.

"Mr. Marconi is to be congratulated on the result of his enterprise. The newspaper press of this and other countries has taken the matter up, popular magazine articles have been written about it, and so now at length the British Public has heard, apparently for the first time, that there are such things as electric waves that can travel across space and through apparent obstacles to a considerable distance, and can there be detected in a startling fashion. Thus the public has been educated by a secret box more than it could have been by many volumes of Philosophical *Transactions* and Physical Society *Proceedings*. Our old friends the Hertz waves and coherers have entered upon their stage of notoriety, and have become affairs of national and almost international importance. Every daily paper now has bulletins concerning the progress of the practical application of the invention, except in so far as it is still being privately worked at by uninfluential individuals."

IV

In his early experiments Marconi used two solid brass spheres 11 cm. in diameter and separated by 1 mm. With a 6-in. Ruhmkorff coil they radiated waves 25 cm. in length. The spheres were fixed in an oil-tight case of parchment or ebonite so that an outside hemisphere of each sphere was exposed, the other being hidden in vaseline oil, the advantages of which have already been explained. It may here be remarked that Marconi subsequently discarded the use of oil, as he believed that it did not give the advantages attributed to it.[1] Two smaller balls, of solid brass, were fixed in line with the larger ones, about 2·5 cm. apart and connected each to one terminal of the secondary winding of the spark coil, the primary winding of which was excited by a few cells, the current being controlled by a Morse key.

Marconi found that the efficiency of the transmitter depended largely on the power and constant performance of the induction coil, and that although a coil giving a 6-in. spark enabled signals to be sent over three or four miles, for greater distances 20-in. sparks were necessary.

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[1] *Journal, Institution of Electrical Engineers*, No. 139, p. 311.

The aerial consisted of an insulated wire connected to one knob of the exciter. It terminated in a sheet of wire netting, called the " capacity area ", placed at the top of a mast. The second knob of the exciter was connected to earth, and the aerial and earth arrangements at the receiving station were similarly arranged, except that the coherer was substituted for the transmitter (Fig. 29).

Marconi believed that the range of the transmitter increased with the size of the capacity areas and with their distance from each other and with their distance from the earth. Where stations were separated from each other by elevations of the ground, or by buildings, he preferred to modify this arrangement by using a single metal plate, attached by an insulator to a tall mast and connected with one end of the exciter at the receiver respectively, and connected from the other end to earth. In some cases the capacity areas were flat plates, hung vertically, but in other they were bent into the form of cylinders, covered at one end and hung on the posts, resembling top-hats on a stick. He subsequently came to the conclusion, however, that the improved results did not depend upon the height of the capacity area from the earth, but were due to the increased length of the wire connecting it to the apparatus. He therefore eliminated the capacity areas entirely and employed instead only a vertical wire, carried by a mast or—in the case of exceptional long-distance experiments—by a kite or balloon. Marconi's elevated aerial wire (or

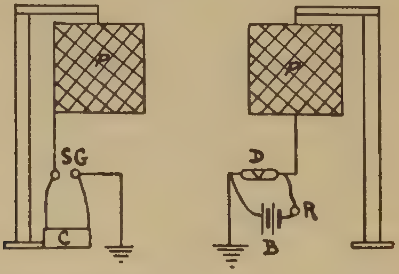

Fig. 29—Marconi's "capacity areas" (p)

sg. Spark-gap. c. Coil. d. Coherer. r. Recording instrument. b. Local battery.

antenna, as it was called) became the basis of all systems of wireless.[1]

The most important part of the receiver was, of course, the coherer, which was connected on one side with the vertical conductor and on the other side to earth. The coherer was included in the circuit of a sensitive relay and a weak battery, and so closed the circuit of a stronger battery in which is inserted the telegraphic receiver or telephone.

When Marconi first became acquainted with the coherer of Branly, it was not out of the experimental stage and was untrustworthy and capricious. He concentrated on it, however, and in his hands it became a very sensitive and reliable instrument. He reduced its dimensions, using a glass tube of some 4 cm. in length and of 2·5 mm. internal diameter. This tube contained two closely fitting silver cylinders with even and parallel ends turned one towards the other and separated by about half a millimetre, the space between being filled with metal filings (Fig. 30).

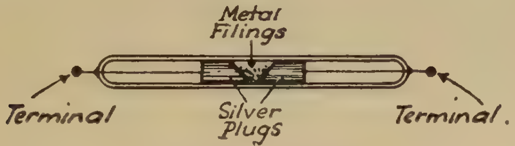

FIG. 30—THE COHERER

Subsequently many different metals were tested until it was decided that the most favourable was a mixture of 96 per cent. nickel to 4 per cent. of silver filings, the addition of silver being found to considerably increase the sensitiveness of the whole. It was noticed that although an increase in the proportion of the silver filings further increased the sensitiveness, it impaired the reliability of the apparatus. A trace of quicksilver was also found to increase the sensitivity. Then the choice of size of the individual filings had to be carefully determined. As a general rule, although the distance between the silver cylinders might vary within certain limits, the wider the gap the larger must the individual filings be. Generally it was found that a narrow space—about half a millimetre—with fine filings was most suitable. External connection to the silver cylinders was made by platinum wires let into the glass tube. A lateral addition to the tube enabled an air-pump to be connected to it and the air exhausted to about one-thousandth of an atmosphere, which though not essential was desirable, as it prevented the oxidization of the filings. A coherer was only judged efficient when it would respond to the inductive effect of an ordinary electrical bell at a distance of a yard or two from the tube.

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[1] See p. 29, Judgment of William K. Townsend (11th April, 1905) of the United States Circuit Court, in which the validity of Marconi's original patent was upheld.

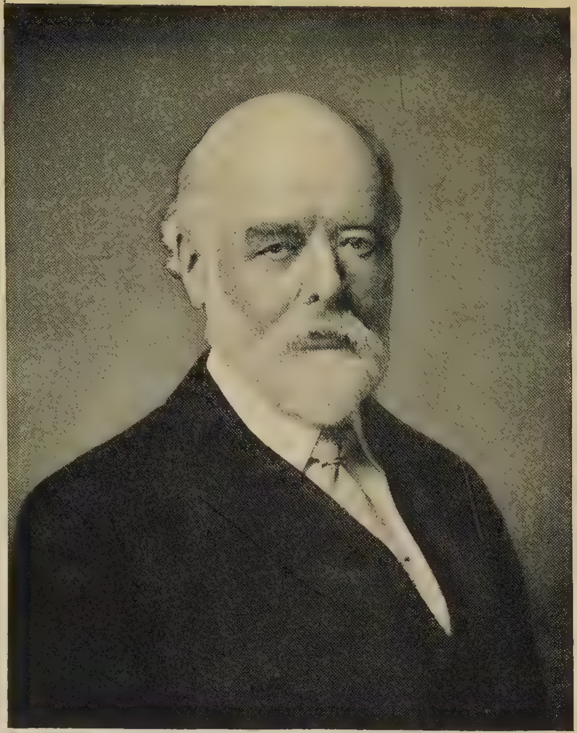
V

Marconi's first transmissions in this country were made from a room in the General Post Office, London, to a receiving apparatus installed on a roof over 100 yards distant. The experiments were quite successful, even though several walls intervened, and Marconi then removed his apparatus to Salisbury Plain, where it was subjected to more severe tests. Here (in 1896) he succeeded in transmitting and receiving signals over nearly two miles, before representatives of the Army and Navy. Further experiments were conducted in May, 1897, across the Bristol Channel, between Lavernock Point and Flatholm (3⅓ miles), and between Lavernock and Brean Down, near Weston-super-Mare (about 9 miles). In these latter experiments Marconi discarded the roughly made parabolic copper reflectors used in the earlier tests. Vertical "air wires" 150 ft. in height were used and a coil that gave a 20-in. spark.

On the cliff at Lavernock Point, some 60 ft. above sea-level, the receiving apparatus was installed. It was connected to a zinc cap, 6 ft. in length and 3 ft. in diameter, fixed at the top of a 90-ft. pole, by an insulated copper wire. An earth-wire ran down the cliff into the sea, and a 20-in. coil, with an eight-cell battery, completed the apparatus.

On 10th May, Preece's electro-magnetic method was successfully demonstrated, and then Marconi's method was given a trial. On the 11th and 12th May his experiments were complete failures. For two days the signals were not received and the fate of the new system trembled in the balance. On the morning of the 13th some one had an inspiration, and the

PLATE XV



OLIVER J. LODGE
(b. 1851)

GUGLIELMO MARCONI
(b. 1874)

receiver was carried down on to the beach, adding another 60 ft. of wire in the down lead from the zinc cap, making it 150 ft. in all. The additional wire made all the difference, for signals now came through clearly, and the situation was saved.

Professor Slaby, of Charlottenburg, who witnessed these experiments, described his feelings on this memorable and historic occasion:

> "It will be for me an ineffaceable recollection. Five of us stood round the apparatus in a wooden shed as a shelter from the gale, with eyes and ears directed towards the instruments with an attention that was almost painful, and waited for the hoisting of a flag, which was the signal that all was ready. Instantaneously we heard the first '*tic-tac, tic-tac*', and saw the Morse instrument print the signals that came to us silently and invisibly from the island rock, whose contour was scarcely visible to the naked eye—came to us dancing on that unknown and mysterious agent, the ether!"

VI

These experiments were followed by trials at Spezia (11th–18th July, 1897), carried out by Marconi at the request of the Italian Government, whose attention had been attracted by the success of the experiments in England. During the first three days excellent results were obtained between land stations at a distance of 3½ km. On the 14th the transmitter—with a vertical wire 78 ft. in length and terminating in a zinc plate—was installed near the arsenal of St. Bartholomew, on the eastern side of the Gulf of Spezia. The apparatus included an oscillator, with two central spheres 10 cm. in diameter and two outer spheres of 5 cm. diameter, and an induction coil—giving a 25-cm. spark—supplied by accumulators. The receiver was placed on board a tug-boat, moored at various distances from the shore. The vertical receiving wire on the tug was 48 ft. in height, ran to the top of the mast, and terminated in a zinc plate, another wire leading from the coherer into the sea. Transmission was successful up to 4 km., but was interrupted by atmospherics.

On the 15th July the vertical wire of the transmitter was lengthened to 90 ft., and although signals were at first interrupted by thunder-clouds and consequent atmospherics, satisfactory transmissions were subsequently made up to

5½ km., when the tug-boat disappeared behind a headland and the signals ceased. On the following day the vessel remained in sight of the transmitting station and messages were sent up to 13 km. On the 17th and 18th the wire at the transmitting station was increased to over 111 ft. in length and the receiver transferred to an ironclad, the *San Martino*, where thev ertical wire was at first 55 ft. and later 90 ft. in length. Messages were then transmitted up to 18 km.

During these experimental transmissions to ships it was noticed that when the funnels, masts, and wire ropes were in line with the shore apparatus, reception was weak owing to the screening effect of the metal. A more serious difficulty was encountered, in that when the vessel was cut off from view at the transmitting station by a headland, signals ceased altogether.

Resulting from the Spezia experiments, Marconi confirmed an earlier observation in regard to the influence of the height of the vertical aerial wire on the distance over which signals can be transmitted.

> "The results", he said, "showed that the distance at which signals could be obtained varied approximately as the square of the height of the capacity areas from earth, or, perhaps, as the square of the length of the vertical conductors. This law furnishes us with a safe means of calculating what length the vertical wire should be in order to obtain results at a given distance. The law has never failed to give the expected results *across clear space* in any installation I have carried out, although it usually seems that the distance actually obtained is slightly in excess. I find that, with parity of other conditions, vertical wires 20 ft. in length are sufficient for communicating one mile, 40 ft. four miles, 80 ft. sixteen miles, and so on.
>
> "Professor Ascoli has confirmed this law, and demonstrated mathematically, using Neumann's formula, that the inductive action is proportional to the square of the length of one of the two conductors, if the two are vertical and of equal length, and in simple inverse proportion of the distance between them. Therefore the intensity of the induced oscillation does not diminish with the increase of distance if the length of the vertical conductors is increased in proportion, or as the square root of the distance. That is, if the height of the wire is doubled, the possible distance becomes quadrupled."

Hertz had shown that his waves pass without appreciable obstruction through doors, walls, and other non-conducting bodies. In actual practice, however, Marconi found that trees, buildings, hills, and similar obstacles absorb the waves. Marconi carried out further experiments to overcome this difficulty, which he found to be surmountable, to a great extent, by increasing the height of the vertical aerial wires and by increasing the power of the transmitter and sensitivity of the receiving apparatus.

VII

As we have already seen, Professor Slaby had witnessed Marconi's first trials in the Bristol Channel. On his return to Germany Slaby experimented (September, 1897) at Charlottenburg, and later in the grounds of the Imperial Palace at Potsdam. He came to the conclusion that for satisfactory transmissions it was necessary that the vertical conductors of both stations should be in sight of each other. Curiously enough, he found that the sail of a boat, the smoke of a small steamer, or even a strong wind (!) intervening between the two stations were " sufficient at times to turn the signals aside ".

In October, 1897, Slaby carried out further experiments on a larger scale near Berlin. He used captive balloons to support his vertical wire at heights varying from 750 ft. to 850 ft. Transmission was effected over 21 km., which, at that time, was the maximum distance that had been attained.

In December Slaby announced his success in sending, with only one wire, two different messages simultaneously without interfering with each other. In the *Electrical Engineer*, 3rd December, 1897, he explained his theory that the continuous current used in ordinary telegraphy is conducted along the centre of the wire. He proved that electric waves on their passage through the ether are attracted by wires that they meet, and that they travel along the outside of those wires without influencing the interior. In making use of these observations he claimed to have succeeded in sending a wave message along the outside of the wire while another message was proceeding through the centre by the continuous current.

Slaby also pointed out that, in conjunction with Dr. Dietz, he had made many experiments with " spark telegraphy " before Marconi's inventions were made public. In his book, *Die Funkentelegraphie* (Berlin, 1897), he acknowledges Marconi's merits in the following words :

> " Like many others, I also had taken up this study, but never got beyond the limits of our High School. Even with the aid of parabolic reflectors and great capacity of apparatus I could not attain any further. Marconi has made a discovery. He worked with means the full importance of which had not been recognized, and which alone explain the secret of his success. I should have said this at the commencement of my subject, as latterly, especially in the English technical press, the novelty of Marconi's process was denied. The production of the Hertzian waves, their radiation through space, the sensitiveness of the electric eye, all were known. Very good ; but with these means 50 m. were attained, but no more."

VIII

The further course of Marconi's experiment was well given by the chairman of the Wireless Telegraph and Signal Company (which later became Marconi's Wireless Telegraph Co., Ltd.) in an address, 7th October, 1898 :

> " A year ago," he says, " when this company was started (July, 1897), Mr. Marconi happened to be in Italy making experiments for the Italian Government and for the King and Queen at the Quirinal. On his return to this country the first long-distance trial was made between Bath and Salisbury. The receiver in this case was given to a post-office official, who went to Bath and by himself rigged up a station, at which he received signals 34 miles distant from where they were sent at Salisbury. After this we put a permanent station at Alum Bay, Isle of Wight. This station, at first, was used in connection with a small steamer that cruised about in the neighbourhood of Bournemouth, Boscombe, Poole Bay, and Swanage, a distance of 18 miles from the Needles Hotel station, with which it was in constant telegraphic communication.
>
> " Various exhibitions were given later—one at the House of Commons, where a station was erected, and another station at St. Thomas's Hospital opposite (May, 1898). Within an hour of the time our assistants arrived to put up the installation, the system was at work. We had many exhibitions at our offices, at which a number of people attended ; amongst others Mr. Brinton, a director of the Donald Currie line of steamers, who asked if we could report a ship passing our station. This was done. The ship was the *Carisbrooke Castle*, on her first voyage out, and as she passed the Needles a message reporting the fact was wirelessly telegraphed to Bournemouth, and there put on the ordinary telegraph wires for transmission to Mr. Brinton.

"After this Lord Kelvin visited our station at Alum Bay, and expressed himself highly pleased with all he saw. He sent several telegrams, via Bournemouth, to his friends, for each of which he insisted on paying one shilling royalty, wishing in this way to show his appreciation of the system and to illustrate its fitness for commercial uses. The following day the Italian Ambassador visited the station. Among other messages, he sent a long telegram addressed to the aide-de-camp of the King of Italy. As it was in Italian, and as Mr. Marconi's assistant at Bournemouth had no knowledge of that language, it may be taken as a severe test—as, in fact, a code message. The telegram was received exactly as it was sent. Previously, we had a display for the *Electrical Review* and *The Times*, both of which papers sent representatives. They put the system to every possible test, and, among others, sent a long code message, which had to be repeated back. In their reports they stated that this was done exactly as sent.

"In May, Lloyd's desired to have an illustration of the possibility of signalling between Ballycastle and Rathlin Island in the North of Ireland. The distance between the two positions is 7½ miles, of which about four are overland and the remainder across the sea, a high cliff also intervening between the two positions. At Ballycastle a pole 70 ft. in height was used to support the wire, and at Rathlin a vertical conductor was supported by the lighthouse 80 ft. in height. Signalling was found quite possible between the two points, but it was thought desirable to bring the height of the pole at Ballycastle to 100 ft., as the proximity of the lighthouse to the wire at Rathlin seemed to diminish the effectiveness of that station. At Rathlin we found that the lighthouse-keepers were not long in learning how to work the instruments, and after the sad accident which happened to poor Mr. Glanville, that installation was worked by them alone, there being no expert on the island at the time.

"Following this, in July, 1898, we were requested by a Dublin paper, the *Daily Express*, to report the Kingstown regatta. In order to do this we erected a [land] station at Kingstown and another on board a steamer that followed the yachts. A telephone wire connected the Kingstown station with the *Daily Express* offices, and as the messages came from the ship they were telephoned to Dublin and published in successive editions of the evening papers.

"After this, Mr. Marconi was requested to put a station at Osborne to connect with the Prince of Wales's yacht *Osborne*. Bulletins of the Prince's health (His Royal Highness, as we all know, met with a lamentable accident just before then) were reported to Her Majesty; not only that, but Royalty made great use of our system during the Cowes Week. After the regatta had concluded the Prince wished to cruise about, and he did so as far as Bembridge on one occasion. The next day they went over to the Needles, at the opposite side of the Isle of Wight. The royal yacht was kept in telegraphic communication with the Osborne station on the first day. On the second occasion they were able not only to communicate with Osborne but also with our station at the Needles Hotel. They rang up the Needles Hotel when 7 or 8 miles away, and immediately had a reply, although about the highest land in the Isle of Wight lay between the royal yacht and the Needles Hotel station.

" Within the last few days we have had to move our station at Bournemouth 4 miles farther west, where we have put up the same instruments, the same pole, and everything at the Haven Hotel, Poole, which is 18 miles from Alum Bay. This increase of distance has no detrimental effect on our work ; in fact, it seems rather easier, if anything, to receive signals at the Haven Hotel than at our former station ; thus, the height of the conductor at Bournemouth was 150 ft., but this is now reduced to 100 ft., which is a very great improvement.

" The vertical conductors are stranded $\frac{7}{20}$ copper wire insulated with india-rubber and tape. A 10-in. spark induction coil is used at each station, worked by a battery of 100 Obach cells, M size, the current taken by the coil being 14 volts of from 6 to 9 amperes. The sparks take place between two small spheres about 1 in. diameter, this form of transmitter having been found more simple and more effective than the Righi exciter previously used. The length of spark is adjusted to about 1 cm., which, being much shorter than the coil can give, allows a large margin for any irregularity that may occur. No care is now taken to polish the spheres at the place where the sparks occur, as working seems better with dull spheres than with polished ones.

" We have sent our assistants to various countries to make demonstrations in connection with our patent rights ; and lately we sent one of our staff to Malta, where some excellent experiments were carried out for the Government officials.

" The Marconi invention is the only (electric) telegraph by means of which a moving object can be kept in communication with any other moving object, or a fixed station, and therefore anyone can see the great use of the invention, not only to the Royal Navy authorities but also to the mercantile marine. A ship fitted with Mr. Marconi's apparatus can not only keep in telegraphic communication with the shore up to any reasonable distance—it has been thoroughly tested up to 25 miles off the shore—but ships can also, if properly equipped, be warned of approaching danger or their proximity to dangerous coasts that are fitted with the wireless apparatus.

" The weather has no effect—at any rate no adverse effect. The only thing we find is that on a foggy day, when a place is obscured, everything is made easier for us. Our worst electrical day is a fine, bright, sunny day in July, when everything can be seen ; but directly everything becomes obscured the facilities of wireless telegraphy are increased. I had a telegram handed to me just as I came in, querying if the Government or the Post Office were not, as has been reported, trying to stop us. So far from that being the case, they have actually requested us to put the system up between Guernsey and Sark; and they have offered us a post office at each end for the instruments. That matter is occupying our attention, and we shall go on with it at once. Also, as we wish to work the thing in France as well as in England, we now intend to put up a station between Calais and Dover. There is not the least doubt of success being achieved, because we are doing a parallel distance to-day without the slightest difficulty. The sea between Calais and Dover is the same sea as between the Isle of Wight and Poole, so the things being equal in both cases we may expect the same success between Calais and Dover as between the other points.

"In December of last year the Company thought it desirable to demonstrate that the system was available for telegraphic communication between lightships and the shore. This, as you are aware, is a matter of much importance, as all other systems tried so far have failed. The cables by which ships are connected are exceedingly expensive, and require special moorings and fittings, which are troublesome to maintain and liable to break in storms. The officials of Trinity House offered us the opportunity of demonstrating to them the utility of the system between the South Foreland Lighthouse and one of the following light-vessels—viz. the Gull, the South Goodwin, and the East Goodwin. We naturally chose the one farthest away—the East Goodwin—which is just 12 miles from the South Foreland Lighthouse.

"The apparatus was taken on board in an open boat and rigged up in one afternoon. The installation started working from the very first, 24th December, without the slightest difficulty. The system has continued to work admirably through all the storms, which during this year have been remarkable for their continuance and severity. On one occasion, during a big gale in January last, a very heavy sea struck the ship, carrying part of her bulwarks away. The report of this mishap was promptly telegraphed to the superintendent of Trinity House, with all details of the damage sustained.

"The height of the wire on board the ship is 80 ft., the mast being for 60 ft. of its length of iron, and the remainder of wood. The aerial wire is led down among a great number of metal stays and chains, which do not appear to have any detrimental effect on the strength of the signals. The instruments are placed in the aft-cabin, and the aerial wire comes through the framework of a skylight, from which it is insulated by means of a rubber pipe. As usual, a 10-in. coil is used, worked by a battery of dry cells, the current taken being about 6 to 8 amperes at 14 volts.

"Various members of the crew learned in two days how to send and receive, and, in fact, how to run the station; and owing to the assistant on board not being as good a sailor as the instruments have proved to be, nearly all the messages during very bad weather are sent and received by these men, who, previous to our visit to the ship, had probably never heard of wireless telegraphy, and were certainly unacquainted with even the rudiments of electricity. It is remarkable that wireless telegraphy, which has been considered by some as rather uncertain, or that might work one day and not the next, has proved in this case to be more reliable, even under such unfavourable conditions, than the ordinary land wires, very many of which were broken down in the storms of last month.[1]

" The instruments at the South Foreland Lighthouse are similar to those used on the ship ; but as we contemplate making some long-distance tests from the South Foreland to the coast of France, the height of the pole is much greater than would be necessary for the lightship installation alone."

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[1] i.e. September, 1898.

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CHAPTER XVII

MARCONI SIGNALS TO FRANCE AND BRIDGES THE ATLANTIC; OLIVER LODGE, THE PIONEER OF TUNING

IN March the following year (1899) an attempt was made to bridge the English Channel, and on the 27th signals passed between the South Foreland Lighthouse and Wimereux, near Boulogne (about 28 miles) and naturally created considerable public excitement. The following report explains what took place on this occasion :

" On this side of the Channel the operations took place, by permission of the Trinity House, in a little room in the front part of the engine-house from which the power is derived for the South Foreland lighthouses. The house is on the top of the cliffs overlooking the Channel. The demonstrations are being conducted for the benefit of the French Government, who have the system under observation, and besides Signor Marconi there were present at the Foreland yesterday Colonel Comte du Bontavice de Heussey, French Military Attaché in England ; Captain Ferrie, representing the French Government ; and Captain Fieron, French Naval Attaché in England. During the afternoon a great number of messages in French and English crossed and recrossed between the little room at the South Foreland and the Châlet d'Artois, at Wimereux, near Bologne.

" The whole apparatus stood upon a small table about 3 ft. square in the centre of the room. Underneath the table the space was fitted with about fifty primary cells ; a 10-in. induction coil occupied the centre of the table. The spark is 1½ cm. in length, or about ⅝ in. ; the pole off the top of which the current went into space is 150 ft. in height. The length of spark and power of current were the same as used for communication with the East Goodwin lightship, a fact that seems remarkable when it is considered that the distance over which the messages were sent yesterday was nearly three times as great. The greater distance is compensated for by the increased height of the pole.

" Throughout the whole of the messages sent yesterday there was not once a fault to be detected—everything was clearly and easily recorded. The rate of transmission was about fifteen words a minute." [1]

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[1] The *Daily Graphic*, 30th March, 1899.

The first international wireless press message was sent by *The Times*, and was as follows:

"(*From our Boulogne Correspondent.*)

"WIMEREUX, 28*th March*, 1899.

"Communication between England and the Continent was set up yesterday morning by the Marconi system of wireless telegraphy. The points between which the experiments are being conducted are South Foreland and Wimereux, a village on the French coast two miles north of Boulogne, where a vertical standard wire, 150 ft. in height, has been set up. The distance is 32 miles. The experiments are being carried on in the Morse code. Signor Marconi is here conducting the trials, and is very well satisfied with the results obtained. This message has been transmitted by the Marconi system from Wimereux to the Foreland."

"Up to the present," wrote Professor J. A. Fleming at the time, "none of the other systems of wireless telegraphy employing electric or magnetic agencies has been able to accomplish the same results over equal distances. Without denying that much remains yet to be attained, or that the same may be effected in other ways, it is impossible for anyone to witness the South Foreland and Boulogne experiments without coming to the conclusion that neither captious criticism nor official lethargy should stand in the way of additional opportunities being afforded for a further extension of practical experiments. Wireless telegraphy will not take the place of telegraphy with wires—each has a special field of operations of its own. But the public have a right to ask that the fullest advantage shall be taken of the particular service that ether-wave telegraphy can now render in promoting the greater safety of those at sea; and that, in view of our enormous maritime interests, this country shall not permit itself to be outraced by others in the peaceful contest to apply the outcome of scientific investigations and discoveries in every possible direction to the service of those who are obliged to face the perils of the sea. If scientific research has forged a fresh weapon with which in turn to fight Nature, 'red in tooth and claw', all other questions fade into insignificance in comparison with the inquiry how we can take the utmost advantage of this addition to our resources."[1]

In September, 1899, the British Association held its annual meeting at Dover, while at the same time the Association Française pour l'Avancement des Sciences met at Boulogne. Marconi's apparatus was installed in the Town Hall at Dover, and messages between that place and Wimereux were successfully sent and received. Wimereux was also in direct communication with the Marconi station at Dovercourt, near Harwich, and with Chelmsford. Both places are 135 km. from Wimereux, and the line between the last-named place and Dovercourt is entirely over the sea, except at one point, where it is cut by the North Foreland. About half the distance between Wimereux and Chelmsford is over land. The experiments, for which conductors 150 ft. in height were used, were entirely successful.

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[1] *The Times*, 3rd April, 1899.

II

Earlier in the same year, the *Ibis*, a dispatch boat, was in constant communication with the South Foreland over a distance of about 52 km., with an antenna 70 ft. in height. Signals also passed between the South Foreland Lighthouse and the East Goodwin Lightship, through fog, rain, and storm, without difficulty. This achievement undoubtedly laid the foundation of signalling from ships at sea to land stations.

During the British Naval manœuvres in the same year (1899) three ships were fitted with the Marconi system (the flagship *Alexandria* and the cruisers *Juno* and *Europa*). The two latter exchanged signals up to 60 miles and the *Juno* up to 74 miles.

By the end of 1899 communication between ships and land stations over distances of 80 to 100 miles became an accomplished fact. Shipping companies, realizing the value of the discovery, installed wireless on their ships, and the Marconi Wireless Telegraph Signal Company erected a number of shore stations at various places.

In March, 1900, the Norddeutscher Lloyd Steamship Company adopted Marconi's system, apparatus being installed on the *Kaiser Wilhelm der Grosse*, and also on the Borkum Riff Lightship and the Borkum Lighthouse. During the second half of that year over 580 telegrams were received by the lightship from passing shipping equipped with wireless apparatus and 20 telegrams by the lighthouse. The total number of words transmitted was over 8,000, and the commercial value of the system was undoubtedly realized. Its utility was demonstrated in a dramatic manner when the lightship broke away from its moorings during a gale and was driven out to sea. A wireless message for help resulted in the rescue of the crew, who would certainly have been drowned but for the existence on board of the Marconi apparatus.

In July, 1900, the British Admiralty contracted for the installation of the Marconi system in 26 warships and at six coast stations. It is interesting to note that a stipulation in the contract required the exchange of test signals between ships' stations at Portland and Portsmouth, a distance of 62 miles, with the Dorset hills intervening. These tests were carried out with every satisfaction.

III

Before completing our account of Marconi's early achievements we must pause for a moment to consider the work of another pioneer, Sir Oliver Lodge, who at this stage helped considerably the advance of wireless by the introduction of a most important invention. This was the condition of " syntony ", or " resonance ", as it was called in those days, but more popularly known to-day as tuning, of which Sir Oliver Lodge was the pioneer.

Oliver Joseph Lodge (*b*, Plate XV) was born at Penkhull, near Stoke-on-Trent, on 12th June, 1851. He was sent to the Grammar School at Newport, where he remained until he was 14. On leaving school his father took him into his works and everything pointed to the boy following his father's occupation and becoming a successful potter. During this time, however, he came across some old copies of the *English Mechanics* and a new world opened its doors for him. He had had no teaching in science, and, in fact, did not know there was such a thing, but now he read everything he could during his leisure hours.

Seven years were spent among clay and the potters' wheels before his father would consent to his following his natural inclination. He then sent him to London to study at University College, where he matriculated, took his B.Sc. and D.Sc. degrees in 1881, and was appointed Assistant Professor in Physics. In 1897 he was elected first Professor of Physics and Mathematics at Liverpool University, and was made a Fellow of the Royal Society. In 1888 the University of St. Andrews conferred upon him the honorary degree of LL.D., and in 1900 he was chosen by the Crown as the first Principal of Birmingham University. Two years later the King conferred upon him the honour of knighthood.

Whilst at Liverpool, Lodge commenced a long series of experiments in connection with electrical phenomena, ether, and kindred subjects. As early as 1875 he had been attracted to the subject by the work of Clerk-Maxwell, whose great treatise had been published two years earlier. In his presidential address before the Radio Society on 21st January, 1925, Sir Oliver told us that he had spent the whole of the summer of 1875 in studying the theory of electric waves set forth in Clerk-Maxwell's volume, which excited his enthusiastic interest. It was at that time purely a mathematical speculation, and no one knew either how to excite or how to detect the waves. Later on, however, Hertz and himself had almost simultaneously succeeded in doing this, but the experiments of Hertz had established the actual existence of the waves more satisfactorily than did his.

IV

In March, 1889, Lodge lectured to the Royal Institution on *The Oscillatory Discharge of a Leyden Jar.* He exhibited many of the effects of the waves, both on wires and in free space, with overflow and recoil effects. Although the lecture did not deal with the utilization of the waves for signalling, Sir William Crookes [1] foreshadowed that the waves should make possible actual telegraphic accomplishment. He indicated also the possibility of tuning or selective telegraphy, which did not become possible until 1897.

Lecturing at the Royal Institution on 1st June, 1894, and in the same year at the British Association meeting at Oxford, Lodge repeated all Hertz's experiments and clearly demonstrated the efficiency of the Branly coherer as a detector of electro-magnetic waves over distances up to 150 yards.[2] He showed how the depression of a key in one place would produce a perceptible signal in another—usually the deflection of a spot of light. He employed a Thomson marine speaking galvanometer on which a momentary depression of the key would produce a short signal, a continued depression a long signal—thus giving an equivalent for the dots and dashes of the Morse code—if the Branly coherer were used in conjunction with an automatic decoherer. He used two such forms of tappers, one consisting of an electrical trembler or vibrator mounted on the stand of the coherer, a type that was subsequently improved into a clockwork mechanism that rotated a steel wheel.[1]

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[1] In a brilliant article in the *Fortnightly Review* for February, 1892, vol. li, p. 173.

[2] Lodge used a modified Branly's coherer in the form of an ebonite or glass tube, 7 in. in length and ½ in. in outer diameter. The ends were fitted with copper pistons, which could be regulated to compress the filings with any desired degree of pressure.

Lodge's aim at this time was to get signals on tape with a siphon recorder, and not to be satisfied with mere telephonic detection. Although he subsequently succeeded in his endeavour, he has since pointed out that more rapid progress would have been made had he concentrated on the telephone. He tells us that :

> " Signalling was easily carried on from a distance through walls and other obstacles, an emitter being outside and a galvanometer detector inside the room. Distance without obstacle was no difficulty in these experiments, only free distance is not very easy to get in a town, and stupidly enough no attempt was made to apply any but the feeblest power so as to test how far the disturbance could really be detected. Mr. Rutherford, however, with a magnetic detector of his own invention, constructed on a totally different principle, and probably much less sensitive than a coherer, did make the attempt and succeeded,[2] signalling across half a mile full of intervening streets and houses at Cambridge." [3]

Writing more recently of his failure to grasp the glorious opportunity thus presented to him, Lodge said : " I was too busy with teaching work to take up telegraphic or any other development. Nor had I the foresight to perceive, what has turned out to be, its extraordinary importance to the Navy, the merchant service, and, indeed, land and war service, too." [4]

On 11th May, 1898, a complete set of Lodge's apparatus was shown working at the Royal Society Conversazione. Instead of the Morse key generally used, Dr. Alexander

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[1] Rupp, of Stuttgard, proposed an alternative method of decohering the filings by making the coherer revolve on its axis—see *Electrical Review*, 22nd April, 1898.

[2] See *Phil. Trans.*, 1897, for report of his paper communicated to the Royal Society in June, 1896.

[3] Lodge : *Signalling Without Wires*, p. 67.

[4] *Wireless Weekly*, 26th September, 1923.

Muirhead's automatic transmitter with punched tape was employed at one end of the room, and a siphon recorder was connected to the receiving apparatus at the other end. The apparatus worked well, as it always had done, and it is remarkable to think that although wireless telegraphy, for which scientists had been searching for over a century, was at this time well within his grasp, Lodge failed to seize the opportunity of turning the discoveries of Hertz and Branly to practical value. He made no attempt to try out his apparatus, but confined his experiments to the laboratory and the lecture-room.

Whatever regrets there may be, however, of opportunities lost, we must agree with Professor J. H. Poynting, F.R.S., when he says, in his admirable biography, " Whatever developments and changes may be made in the system of wireless telegraphy, there can be no doubt that Sir Oliver Lodge will always be recognized as one of the founders of the system, as a pioneer in researches upon which others have built ". For his research work in wireless matters and his general contributions to science, Lodge received, in 1898, the Rumford Medal of the Royal Society, one of the highest honours that the Society can bestow, and one that is not confined to our own countrymen.

As particulars of Lodge's experiments of 1894 had been published, it was, according to British law, unpatentable in this country. That it was of value and patentable for telegraphic purposes is clear, however, from his United States patent [1] granted only after long discussion on the strength of work recorded in 1894, since it could be proved to have been introduced into the United States in that year.

V

One of the great objections to Marconi's system, which became more serious with every additional transmitter, was that there was no privacy in the messages transmitted. Also, with a number of stations working at the same time there was a general interference that amounted at any rate to difficulty in working, if not a general confusion, and threatened to place serious limitations on the practical applications of any system of wireless.

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[1] No. 674846, dated 21st May, 1901—application filed 20th December, 1897.

In 1897 Lodge called attention to the greatly improved results to be obtained from tuning the transmitter and receiver. He showed that some degree of privacy could be obtained and unwanted messages eliminated to a certain extent. Some of his suggestions in this connection were embodied in his patent (10th May, 1897) for " Improvements in Syntonized Telegraphy Without Line Wires ".[1] This patent was legally established by Lord Moulton as the fundamental tuning patent and without it the Marconi system could never have grown and expanded as it has. It is interesting to remark that it has been this patent that has been upheld time after time in the courts. It was acquired by the Marconi Company in 1911, after it had been specially extended for an additional seven years by Lord Justice Parker. The basic nature of the invention is instanced by the fact that only a few years ago the Admiralty were condemned by Lord Moulton, sitting as Arbitrator, to pay compensation in the nature of royalty to the patentee, on the basis of user throughout the whole period of the life of the patent—21 years. " This invention ", said Professor G. W. O. Howe, " shows a remarkably clear insight into the problem of tuning and selectivity, and constitutes a great advance. . . ." [2] " During the years between 1896 and 1910 ", said Professor W. H. Eccles in 1922, " Marconi, aided by Lodge's invention of the tuning-coil, carried wireless telegraphy substantially to its present form." [3]

In Marconi's original system, transmission was effected by storing energy in the aerial, which was charged directly. The small amount of energy thus available was radiated as waves that were highly damped and rapidly diminished in amplitude. If the sending key was depressed for an appreciable time, the waves became a series of irregularly spaced " kicks ", and not only was the range limited, but tuning was out of the question.

As we have seen, Marconi first used an induction coil with a battery connected to the primary circuit. The secondary circuit was connected directly to the spark-gap, one ball of which was connected to earth and the other to the aerial

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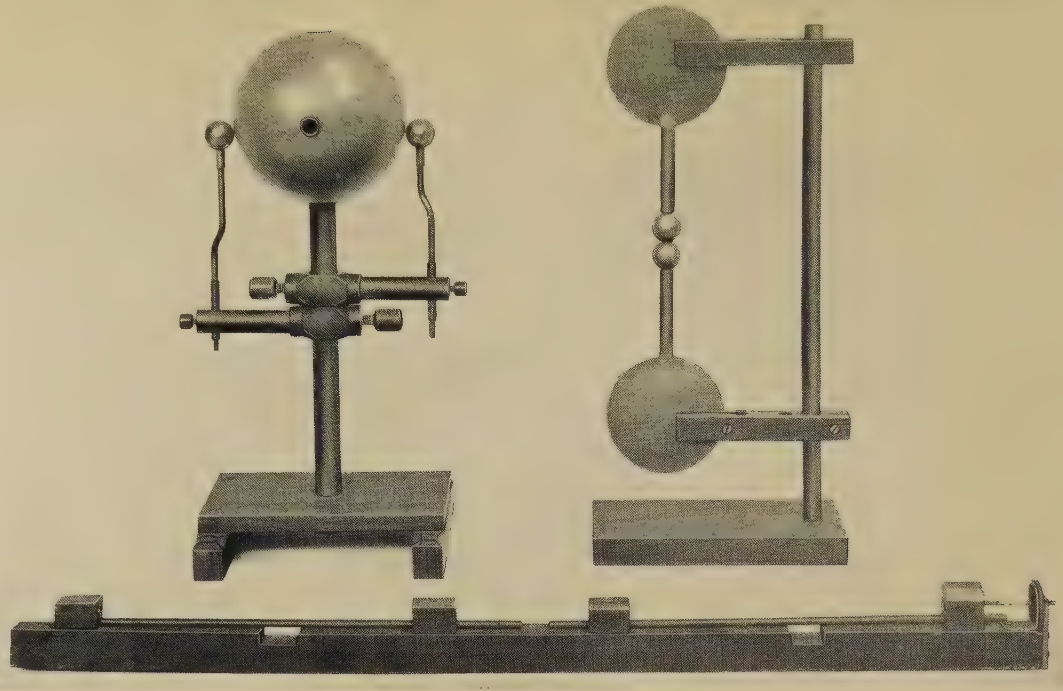
[1] British Patent No. 11575, U.S. Patent No. 609154.

[2] *Year Book of Wireless Telegraphy*, 1921.

[3] *Journal of the Royal Society of Arts*, 9th June, 1922.



LODGE SPHERICAL OSCILLATOR (1894) (LEFT)
HERTZ OSCILLATOR (1894) (RIGHT)
HERTZ RESONATOR (1894) (BELOW)

(Fig. 31). In 1900 he introduced an improved apparatus in which was a modified Leyden jar or " condenser ", and a coil of wire, the discharge being through the induction coil, across a spark-gap as before. In the inventor's own words: " This arrangement enabled much more energy to be imparted to the radiator than heretofore, the closed circuit of the primary being a good conserver, and the open circuit of the secondary a good radiator, of wave energy." Lodge's suggestion for tuning the transmitter was also adopted by connecting one terminal of a second coil to the aerial and leading its other terminal to earth (Fig. 32).

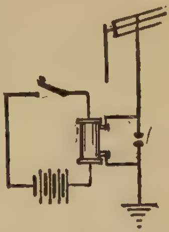


FIG. 31—MARCONI'S EARLY METHOD

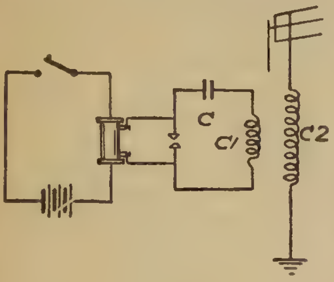


FIG. 32

The same method as shown in Fig. 31, but with condenser (*c*) and tuning coils (*c*1, *c*2) added.

There were thus two distinct circuits; the first composed of the induction coil, the condenser, and the primary tuning coil; and the second of the aerial and the secondary tuning coil. The two circuits were tuned one with the other, thus causing the oscillations set up by the rapid charge and discharge of the condenser to be repeated by induction as sympathetic oscillations in the aerial. Not only was the energy thus radiated very much more powerful, but the waves decreased only slowly in amplitude. The receiver was also improved, a tuning coil being introduced and the primary and the secondary circuits tuned, as in the case of the transmitter (Fig. 33). All four circuits were thus in tune with each other.

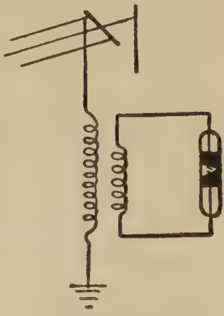


FIG. 33
TUNED RECEIVER

This arrangement was protected by the famous "four sevens" patent [1] filed by Marconi on 26th April, 1900, in which, for the first time, a closed tuned circuit is coupled to a similarly tuned open aerial circuit at the transmitting and receiving ends. The patent gave the Marconi Company almost a monopoly of syntonic wireless telegraphy in England and America for a time.

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[1] British Patent No. 7777, U.S. Patent No. 763772.

VI

To come now to Marconi's crowning achievement—the bridging of the Atlantic. Although Marconi had enormously improved the Branly coherer in sensitivity, it became increasingly evident as time went on that a more sensitive detector would have to be found, if wireless was to be a commercial success. We have already seen that even up to the time of the introduction of tuning, Marconi was using the Branly coherer, which was unsatisfactory, not only because it required frequent adjustment, but also because it was not sufficiently sensitive. It was so slow in its working that a maximum speed of only 16 or 18 words per minute could be attained. As it could only be used over comparatively short distances, it was altogether unsuitable for high-speed and long-distance commercial working.

Marconi, therefore, commenced experiments in order to further develop his apparatus, and in 1902 patented his magnetic detector (*b*, Plate XI).[1] This consisted of an endless moving band of soft-iron wire, mounted on two wooden pulleys rotated by clockwork and passing close to the poles of two horseshoe magnets. The principle of this detector depended on the fact that as the moving band passed from the influence of one magnet to that of another, the magnetism became reversed. The change was not accomplished instantaneously, however, but occupied a certain minute fraction of time to complete. This is accounted for by the fact that the iron for a short space of time resists the attempt of one magnet to reverse the effect of the other.

At one place the iron wire passed through two small glass tubes on which was wound silk-covered copper wire. One of these coils was connected to a telephone receiver and the other connected in the aerial circuit (Fig. 34). As we have already learned, Michael Faraday had shown that if a magnet be moved near a coil of wire an electric current is induced in the wire. An exactly similar occurrence takes place if the magnet is stationary and the wire moving, as was the case in Marconi's magnetic detector. Thus, so long as the state of the coil was normal, the magnetic condition of the iron wire remained constant. When electric waves were received by the aerial, however, their impulses instantly caused a reversal of the magnetism in the iron wire. The effect of this sudden moving of the lines of magnetic force was to induce a current in the second coil, the result being the production of an audible "click" in the telephone receiver.

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[1] British Patent No. 10245.

The magnetic detector had the advantage of being always ready for work and requiring no attention, except the winding at intervals of the clockwork mechanism that drove the moving band.

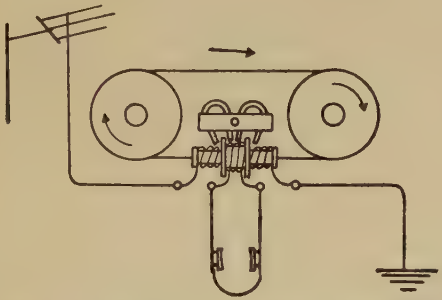

Fig. 34—Marconi's magnetic detector

With this improved apparatus Marconi sent (in January, 1901) signals from St. Catherine's in the Isle of Wight to the Lizard in Cornwall (155 miles), using a 10-in. spark coil. In this same year the first long-distance station was established at Poldhu in Cornwall (*a*, Plate XVII), which at first had four aerials, each comprised of one hundred thin bare wires of tinned copper. These copper wires were suspended from four steel ropes, stretched between four wooden towers 120 ft. in height and 180 ft. distant from each other. The lower ends of the four sides of wires combined at one point on the roof of the building, and thus formed a gigantic inverted pyramid of wire.

VII

Marconi next turned his attention to an attempt to signal across the Atlantic from this new station. He realized that Leyden jars as condensers, and batteries for power, would not give sufficient energy to accomplish his object. A problem such as this demanded the production of electric waves on a scale greater than had ever been attempted. A 25-h.p. oil engine was therefore installed, along with an alternator that gave a low-frequency current of 2,000 volts. This current was raised to 20,000 volts by transformers and charged a large number of condensers, which were really huge Leyden jars, composed of glass plates coated on each side with tin-foil and immersed in oil in stone containers.

Early in December, 1901, Marconi arrived in Newfoundland, and there for a couple of weeks he, with two assistants, endeavoured to get aloft several huge kites. One, a hexagonal arrangement of bamboo and silk, 9 ft. in length, broke loose and was lost, and others were swept out to sea. A 14-ft. balloon, filled with hydrogen, snapped its mooring wire and disappeared. At length, on the 12th, they managed to get a kite 400 ft. up, in the teeth of a gale, at the foot of Cabot Tower, Signal Hill. A wire from the kite was led into a room of the old barracks, where sat Marconi and his assistant, Kemp, listening for half an hour without result. At last, at 12.30 p.m., they heard the faint dots of the signal, the letter " S ", agreed upon and sent by the operators at Poldhu, 1,800 miles distant. " When Marconi succeeded in sending the letter ' S ' by Morse signals from Cornwall or Ireland to Newfoundland," says Sir Oliver Lodge, " it constituted an epoch in human history on its physical side, and was itself an astonishing and remarkable feat." [1]

Thus the Atlantic was bridged, and transoceanic wireless became an accomplished fact. The public were incredulous at the accomplishment of the seemingly impossible, and their surprise was increased when, the following month, Marconi, on board the liner *Philadelphia* on a voyage to New York, received signals from Poldhu up to a distance of 2,099 miles. It was on this voyage that Marconi found himself " impeded

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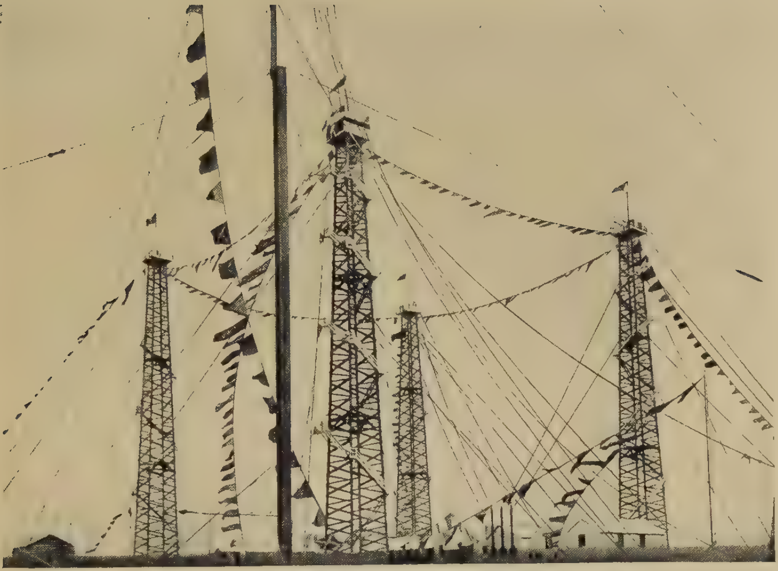
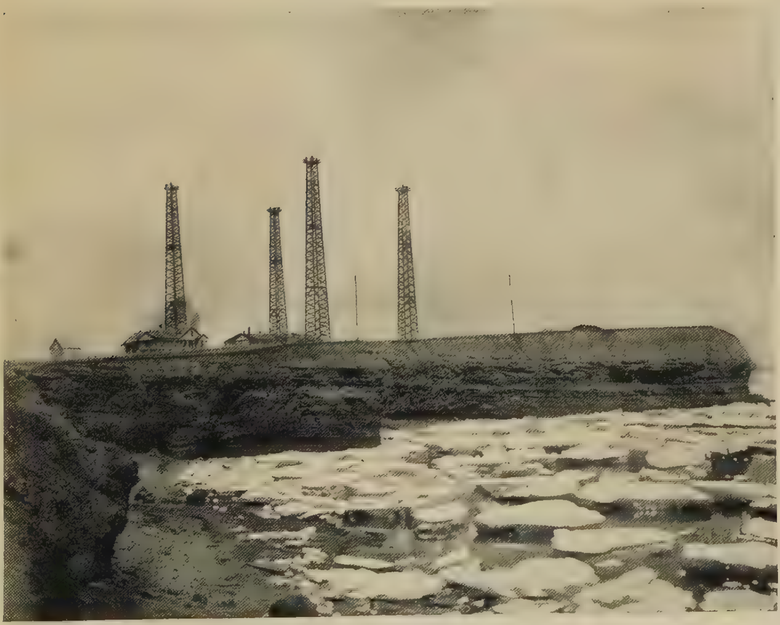
[1] Lodge, *Talks About Wireless*, p. 16.



THE AERIAL MASTS AT POLDHU DECORATED FOR THE VISIT OF KING EDWARD VII, THEN PRINCE OF WALES



THE MARCONI STATION AT GLACE BAY

WORKING MEN'S
COLLEGE
LIBRARY.

by an unforeseen difficulty caused by the effect of sunlight on radio-telegraphic transmissions ". In consequence of the effect of the light he found " that at a distance of more than 700 miles all reception became impossible after sunrise, but with an increase in wave-length this difficulty could be overcome. . . . Thereafter all students of radio-telegraphy devoted themselves to the use of longer and longer waves, and thus, from waves of 1,000 and 2,000 metres, there was a gradual transition to the use of waves that reached the length even of 30 kilometres ".

Towards the end of 1902 new stations were erected at Glace Bay (Cape Breton, Nova Scotia), (*b*, Plate XVII) and Cape Cod (Mass., U.S.A.) for transatlantic communication. It was then decided to build another new station at Clifden (in Galway, West Ireland) for communication with Glace Bay. Here several improvements were introduced, including (in 1907) Marconi's disc discharger, which gave a continuous train of waves interrupted only by the sender's key to form Morse signals. This invention overcame one of the great difficulties experienced with the earlier installations—that of the tendency of the high-tension transformers (used to charge the condenser) to form an electric arc across the spark-discs. The discharger also gave very powerful electric waves of great wave-length, that might be either intermittent or persistent as required. Another improvement was the introduction of air condensers, consisting of insulated metal sheets, suspended in air, in place of the glass and tin-foil previously used.

On 22nd December, 1902, Marconi sent the following wireless telegram to King Edward at Buckingham Palace :

> " On occasion of first wireless telegraphic communication across Atlantic Ocean may I be permitted to present, by means of this wireless message transmitted from Canada to England, my respectful homage to His Majesty the King.
>
> " MARCONI "

At the same time Lord Minto sent to the King the following message :

> " May I be permitted by means of this wireless message to congratulate your Majesty on success of Marconi's great invention connecting England and Canada.
>
> " MINTO "

These messages were suitably acknowledged, the King congratulating Marconi.

Transatlantic communication now became general, and, on 30th March, 1903, *The Times* contracted with the Marconi Telegraph Company for regular transmission of news from the New to the Old World.

In 1904 the first ocean newspaper, *Cunard Daily Bulletin*, was published on the R.M.S. *Campania*, printing news items received by wireless from Poldhu.

Resulting from his experience in the erection of the new station at Clifden, Marconi designed what was at that time the largest station in the world. This was situated at Coltano, near Pisa (Italy), where the power was 400 h.p. (300 kw.). This station maintained regular communication over a distance of 2,238 miles day and night with Massana (East Africa).

VIII

In 1905 Marconi found that signals were heard more strongly when the receiving aerial was directed away from the transmitting station, with the receiving apparatus connected at that end of the aerial nearest to the transmitting station (Fig. 35). In transmitting he found also that signals were stronger in a given direction when a similar aerial arrangement was employed.

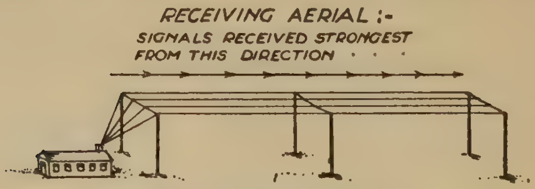


FIG. 35—DIRECTIVE AERIAL

Up to this time vertical antennæ had generally been used, but in these experiments horizontal antennæ were employed, and were found to give greatly improved results. An aerial of this type, used for transmitting, radiates most of its energy in the direction opposite to that to which the free end is directed. The free wires seem to act in a similar way to a reflecting lens in a searchlight, directing and concentrating the rays forward. With horizontal receiving and transmitting aerials placed "back to back", and the free ends pointing away from each other, the range was found to be very much greater than with the vertical and undirective aerials formerly employed.

In 1907 a regular press service was opened and made use of in this country by *The Times*, and in America by the *New York Times*. In the first five months' service over 68,000 words were promptly and efficiently transmitted for the *New York Times*. Soon after, however, the service was interrupted by disaster to the station at Glace Bay, which was burned down. It was decided to build a new station, and also to reconstruct the station at Clifden, and these alterations interrupted the service until 23rd April, 1910.

In 1910 the Post Office took over the Marconi coast stations in Great Britain, and a scheme was entered into in the following March to establish a chain of wireless stations around the Empire. Stations were to be erected at London, Egypt, Aden, Bangalore (India), Pretoria (South Africa), Singapore, and Hong-Kong, with an extension from Singapore to Port Darwin, where the Australian Government were to erect a station. Bitter discussions subsequently took place in Parliament as to the terms of the agreement, and a revised contract was entered into in 1913.

It was not until 1919 that a commencement was made to erect the stations at Leafield, near Oxford, and Abu Zabal, the Egyptian station near Cairo. The war broke out, and a modified plan was subsequently substituted for the scheme. This consisted of the erection, for communication with ships, of medium-power stations at Jamaica, Bermuda, St. John's, Demerara, Aden, Mauritius, Durban, Port Nolloth, Gambia, Seychelles, Ceylon, Singapore, Hong-Kong, Ascension, and the Falkland Islands—all of which stations proved to be of considerable service during the war.

IX

In the past few years the theory and practice of long-distance transmission has undergone a most important and radical change, showing that it is dependent on circumstances with regard to which our understanding had previously been to a very large degree incomplete, to say the least of it.

As we have already seen, Marconi found (in 1902), during experiments between Poldhu and a ship in the Atlantic, that he was able to get signals up to a distance of 2,000 miles at night, using waves of 2,000 metres, whereas during the day he failed to get them at 700 miles. It had been universally accepted up to that time that short waves, whilst often giving extraordinarily long ranges at night, were incapable of being made to cover long distances by daylight. As a matter of fact, for a period of eight years from 1901 the Marconi Company had installed on a considerable number of ships a system of spark transmitters utilizing waves only 120 metres in length, which was commonly referred to as the "Tune A" system. Although utilizing only a very small amount of energy, it was capable of regularly communicating over a distance of about 100 miles during daytime, but at night the range often exceeded 1,000 miles, although a comparatively insensitive tape receiver was employed. One of the advantages of that system was its comparative freedom from atmospheric disturbance.

These early experiences of short-wave transmission have in recent years been coupled up by Marconi with a system of "beam transmission"[1] that effects very considerable economies in power and equipment and has also many other advantages. In an address to the Royal Society of Arts Marconi said:

> "Wireless waves are far too valuable to be always broadcast in all directions. I cannot understand why, for instance, messages intended for Canada or South Africa should be scattered simultaneously all over the world. It is easy to appreciate the utility of the non-directional system for many naval and marine purposes, but for ordinary efficient communication between fixed places, or between one country and another, the right and logical thing to do, if possible, both from the point of view of secrecy and economy, is to concentrate all the radiated energy into a beam directed towards the country or place with which it is desired to communicate."[2]

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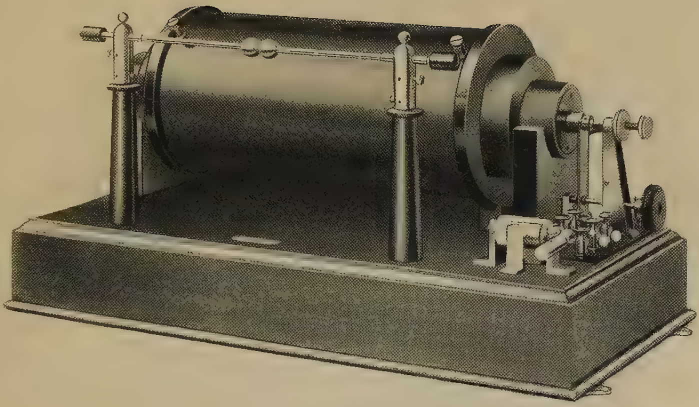
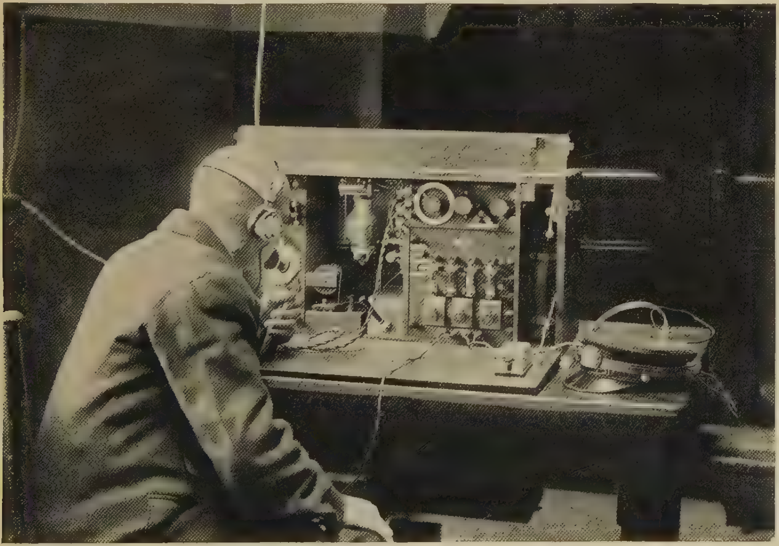
[1] "I always claim for myself the honour of having been the first Fascist in radio-telegraphy, the first to recognize the desirability of uniting in a beam (*fascio*) the electric rays, as the Hon. Mussolini has first recognized in the political field the necessity of uniting in a 'Fascio' the best energies of the country for the greatness of Italy. . . ."—Marconi in a speech (1926) at his native Bologna.

[2] *Electrical Review*, 19th December, 1924, p. 932.



ACTUAL COIL AS USED IN MARCONI'S ORIGINAL EXPERIMENTS (1898)



ONE OF THE FIRST COMMERCIAL WIRELESS INSTALLATIONS BY WHICH THE MERSEY DOCKS AND HARBOUR BOARD WERE ABLE TO KEEP IN CLOSE TOUCH WITH THEIR LIGHTSHIP ON THE MERSEY BAR

With a view to furthering developments on these lines experiments were carried out, transmitting from two stations to Norway, in August, 1921, and at Christiansund day and night telephony was easily received from both stations. During those experiments the curious night distortion of telephone signals was discovered, particularly when transmission was overland. During his experiments on the steam yacht *Elettra*, Marconi discovered that the short waves being used could not only cover great distances by day, and much greater distances by night, but that they were quite reliable and that large parts of continents and ranges of mountains did not materially reduce their working distance.[1]

Describing (in 1924) the series of tests over world-wide distances during the winter, spring, and summer of 1923, Marconi pointed out that " while the limitation of the period of working to practically the hours of darkness constituted an undoubted disadvantage, still the economical advantages, together with the reliability and possibility of working this system at far greater speeds than would have been feasible with the high-powered long-wave installations, went far to convince him that the short-wave beam system would be capable of transmitting a far greater number of words per 24 hours between England and far-distant countries than would be possible by the comparatively powerful, cumbersome, and expensive stations actually in use, or planned to be used, for Imperial commercial communication. It is therefore a satisfaction to be able to state that the stations intended for this purpose in England that the Marconi Company is now erecting under a contract with the Post Office—and others to be installed in the principal Dominions and far-distant countries —will all work on the beam system ".

In 1924 the experiments were extended to cover world-wide ranges between Poldhu, Montreal, New York, Rio de Janeiro, Buenos Ayres, and Sydney. In this work great success was obtained, including the first telephonic communication with Australia, when the sending station used only a power of 20 kw. The signals were received with great strength at New York, Rio de Janeiro, and Buenos Ayres during the time when darkness spread over the whole, or the major part, of the great circle track separating these places from Poldhu, but no signals at all were received when the same space was all, or practically all, illuminated by the sun. This limitation of the period of working to practically the hours of darkness constituted a disadvantage, but the economic advantages, combined with the reliability and the possibility of working at far greater speeds than are possible with high-powered, long wave-length working, convinced Marconi that the older method was doomed to be replaced by the short-wave beam system, and proved an inspiration for further work.

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[1] For further details of developments in short-wave wireless telegraphy, see Marconi's paper, *Radio Telegraphy*, read (on 20th June, 1922) before the American Institute of Electrical Engineers and the Institute of Radio Engineers, New York.

More recent work with wave-lengths of 92 m., 60 m., 47 m., and 32 m. showed that the daylight range of practical communications over long distances increased very rapidly as the wave-length was reduced. With transmission at 32 m. messages were received all day at Beirut from Poldhu, 2,100 miles distant over mountainous land, while the 92-m. waves could not be picked up at Madeira, a distance of 1,100 miles over the sea. Investigations showed that transmissions between Poldhu and Sydney and other distant places were possible at a wave-length of 32 m., with the expenditure of only 1 kw., and for 23½ hours every day. It was also found that messages could be conveyed from Britain to New York, Rio de Janeiro, and Buenos Ayres, while the spaces intervening were exposed to daylight.

During November, 1924, some successful receiving tests were carried out in England from a low-power transmitting station in Australia utilizing an 87-m. wave, whilst in the following month trials were continued with Canada, the United States, Brazil, the Argentine, and Australia, as well as (for the first time) with Bombay and Karachi in India and Cape Town in South Africa. The power utilized at the Poldhu station during all those tests was 15 kw.[1]

The importance of these experiments in wireless transmission cannot be overstated. Low power consumption, low capital costs, and running expenses, the characteristics of the system of short-wave beam transmission, should make possible the reduction of telegraph rates for long-distance communication, in addition to making commercially remunerative the establishment of wireless transmission to the smaller outposts of the Empire.

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[1] For a more detailed account of the development of short-wave wireless telegraphy the reader is referred to an article by Dr. J. A. Fleming ("The Propagation of Wireless Waves of Short Wave-length") in *Nature* (24th January, 1925).

Before the possibilities of the beam system had been investigated the problem of financing high-powered stations was becoming extremely serious. The Post Office station near Rugby, for example, constructed under the earlier system, employs a 1,000-kw. plant and uses a gigantic aerial system, supported by sixteen steel towers, each 820 ft. in height. More recently a station in the Union of South Africa has been built and equipped on the same gigantic scale, and a station at Buenos Ayres, designed primarily for communication with Europe, employs 800 kw. and an aerial supported by ten towers, each 680 ft. in height.

> " Such stations as these will now prove uneconomical and comparatively inefficient for long-distance work. It is interesting to note that in this phase of development the technical side of the work has far outpaced the theory, and we are still far from possessing anything approaching exact knowledge of the conditions governing the propagation of these waves through space. Reflectors of economical and practical dimensions are only efficiently applicable when short waves are used, and seem to be essential for ensuring the carrying out of commercial high-speed transmissions. Their use diminishes fading, and thus increases the margins between which the received signals can be read. A new era has been opened for wireless telegraphy as the result of this recent experimental work, and all who have contributed to it are deserving of the gratitude of the people of the whole civilized world." [1]

X

The conclusion of this particular chapter seems to be a fitting place for the mention of a noteworthy pioneer of wireless—Oliver Heaviside, the originator of the " Heaviside layer " theory. In the history of every science there are records of workers who were content to hide their light under a bushel—whose genius did not shine in the light of day, and whose entry into the scientific arena was unaccompanied by a fanfare of trumpets. Of these, in the story of wireless, there is no more outstanding example than that of Oliver

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[1] *Engineering*, 19th December, 1924.

Heaviside—a modest and retiring man, a contemporary of Sir Oliver Lodge and Dr. Searle of Cambridge, and a mathematician of brilliancy and originality.

Oliver Heaviside (*a*, Plate XIX), the son of Thomas Heaviside, an engraver with a considerable repute as a book illustrator was born in London on 13th May, 1850, and died at Torquay on 4th February, 1925. He came of a family who had close associations with Music, Theology, and Medicine. His uncle was Sir Charles Wheatstone, the first (with Sir William Cooke) to make the telegraph available (in 1837) for public transmission of messages in this country.

In his earlier days Heaviside was in the employ of the Great Northern Telegraph Company at Newcastle-on-Tyne for a few years, but after 1874 he lived a very retired life at Torquay, where he devoted himself to interpreting Clerk-Maxwell's theory of electro-magnetic radiation, more particularly in showing how it can be applied to a solution of the problem of practical telegraphy and telephony, both with or without wires. As was the case with George Boole, Heaviside's mathematical knowledge seems to have been mainly self-acquired. This procedure, if difficult and slow, sometimes results in entirely new light being thrown on certain mathematical problems. The student thrown on his own resources may originate new methods of attack, and thus it was with Heaviside, who further resembled Boole in his reliance on, and skill in, the use of symbolic methods.

He was probably much greater as a philosopher than as an expositor, and the late Professor Perry did good service in explaining more clearly some of Heaviside's methods, and particularly his development of the idea of fractional differentiations and integrations. Everyone knows what is meant by $\frac{dy}{dx}$ or by $\frac{d^2y}{dx^2}$, but Heaviside succeeded in attaching a meaning to such expressions as $\left(\frac{d}{dx}\right)^{\frac{1}{2}} y$, and thus arrived very simply at certain results hitherto only reached by a more complicated analysis. It was by making use of this method that Professor Perry made the first serious attack on Lord Kelvin's figure for the age of the earth.[1]

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[1] The latter is, of course, now completely discredited, but for reasons other than those advanced by Professor Perry.

It seems probable that Heaviside's mathematical methods may be largely employed in the future. One, possibly sanguine, mathematician has expressed in conversation the opinion that his "operators", by providing more direct methods of obtaining the required arithmetical results, will render unnecessary the solution of equations in series of spherical harmonics.[1] This consummation is one undoubtedly to be desired, but sounds too good to be true. The Royal Society did publish one paper by Heaviside on this subject, but a second has merely been stored in the archives, the reason being, it is understood, that certain portions are in conflict with well-established results. It seems probable, however, that some part at least of any paper by so original a thinker must be valuable, and it would be well if this could be sorted out and published.[2] Possibly, some Lord Rayleigh of forty years hence will do the same for Heaviside as the late Lord Rayleigh did for Waterston, whose paper on the kinetic theory of gases, submitted to the Royal Society in 1845, was not published until some forty years later, after other investigators had independently arrived at the most important of the author's conclusions.

Heaviside's most important work was in laying the foundation of the modern theory of telephonic transmission, especially for long-distance work. It is no exaggeration to say that in this connection he saved the governments of every civilized country in the world millions of pounds in the costs of their telephonic schemes. He was one of the first to show that a moving electric charge possesses inertia, a fact that is all important to the modern doctrine of relativity. He discovered and filled in a gap in Lord Kelvin's theory of signalling through a submarine cable, and pointed out that inductance should improve telephonic transmission. On the theory long cherished by the British Post Office, however, self-inductance was harmful to clearness of transmission, and therefore to be avoided. Accordingly the authorities turned a deaf ear to his suggestion, and even professed to have proved its worthlessness by certain experiments they had carried out at Newcastle. But Professor Pupin, President of the American

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[1] It is interesting to add that his "operators" are now being carefully studied by certain mathematicians abroad.

[2] *Engineering*, 13th February, 1925.

Association for the Advancement of Science, demonstrated the advantages of increasing self-inductance by the introduction of loading coils at intervals along the line, and the Western Union were more open to the consideration and adoption of new ideas than the British Post Office.[1] Heaviside's methods were next adopted in the United States and in Germany, and later by the National Telephone Company in this country. Now, many of the submarine telephone cables across the English Channel are loaded, as are thousands of miles of underground cables, the aerial telephone line of 3,400 miles between New York and San Francisco, and others.

To the general public Heaviside's name is known as the originator of the theory of the "Heaviside layer". In the early days of wireless telegraphy, when sceptics were denying the possibilities of electro-magnetic waves travelling over the wide expanse of the Atlantic, Heaviside maintained—on the basis of Clerk-Maxwell's theory—that the conductivity of sea-water would cause the waves to travel on the surface of the sea in a similar manner to that in which they follow a metallic wire. In 1900 he pointed out that in the higher regions of the air there probably exists a conducting layer, of rarefied and ionized gases, now known as the "Heaviside layer". Such a conducting layer, he pointed out, acts as a reflector, so that the wireless waves are confined between this and a second conducting layer formed by the surface of the sea.[2]

Heaviside devoted the whole of his life to the study of

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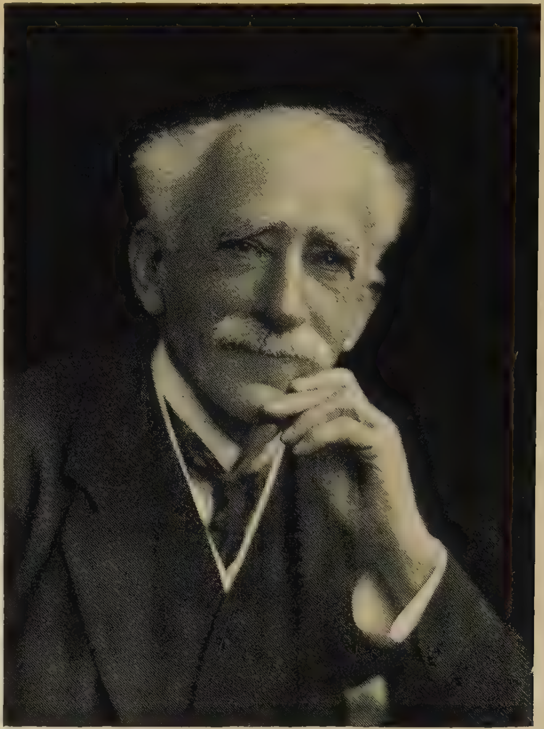
[1] It will, perhaps, be of interest to mention that a very remarkable nickel-iron alloy, called Permalloy, containing 78·5 per cent. of nickel and 21·5 per cent. of iron, was produced a short time ago in the United States by the research engineers of the Western Electric Company. This material, which has one hundred times the magnetic permeability of pure iron for very small magnetizing forces, has been used for the "loading" or over-winding of submarine telegraph cables on the principle first made known by Heaviside. The result has been to increase the speed of signalling two or three times when compared with a similar cable loaded only with pure iron.

[2] Another theory has been put forward by Professor J. A. Fleming, that the waves are reflected by a more or less sharply defined conducting upper layer of the atmosphere containing highly ionized dust flung off by light pressure from the sun. A further explanation was advanced (in 1912) by Dr. W. H. Eccles, who pointed out that mathematical calculations showed that an ionized rarefied atmosphere was capable of increasing the speed of electric waves, so that if the ionization increased from the ground upwards, the top of the wave should travel faster than the foot, and, in due course, should actually lean forward, thereby following the curvature of the earth.

PLATE XIX

OLIVER HEAVISIDE
(1850-1925)



JOHN AMBROSE FLEMING
(b. 1849)

electricity, and was responsible for many remarkable inventions. He worked alone in Torquay, where he received many distinguished scientists from all parts of the world, but otherwise lived a quiet, independent, self-contained life. He published two volumes of *Electrical Papers* in 1893, and his three volumes on *Electro-magnetic Theory* were reprinted in 1922. The mathematical methods explained in his works are fascinating, and have a distinct application in many branches of mathematical physics other than electricity. His constant endeavour seems to have been to show the value of a knowledge of physics and of mathematical theory in the electrical industry. Everything relating to induction; to the energy of electrical currents; to energy in electro-magnetic fields; to the self-inductance of wires and to the generation of electro-magnetic waves, was elaborately worked out, and there is little doubt but that future workers in the science of the ether will make use of his work. He appears to have had a wonderful instinct for grappling with the difficulties of a subject and giving symbolic expression to the inherent difficulty of any problem that he tackled.

In his early years little recognition of Heaviside's great work was accorded him. He was misunderstood, and the telegraphic authorities of his time turned down all his theories. He felt this neglect very keenly, but recognition came at last, and he was elected a Fellow of the Royal Society in 1891. When the Faraday Medal of the Institution of Electrical Engineers was founded in 1922, the Institution honoured itself in making the first award to Heaviside.

Mention must also be made of one of Oliver's brothers, Arthur West Heaviside, of Newcastle-on-Tyne, another pioneer of wireless. He was a Superintending Electrical Engineer to the Post Office, and (as we have already related under the chapter dealing with the work of Sir W. H. Preece) he carried out extensive experiments in connection with wireless transmission by induction for Preece, who was then the Engineer-in-Chief to the Telegraph Department of the Post Office.

It was A. W. Heaviside who (in 1887) tested Preece's theory that a magnetic field exists around telephone wires and that this extends through both earth and air, without interruption (see p. 163).

The rejection of Oliver Heaviside's theories has already been mentioned, and in this connection it is on record that a paper by A. W. Heaviside was also rejected by the Society of Telegraph Engineers because it embodied in practical form the results of his brother's mathematical researches! It is gratifying to learn, however, that A. W. Heaviside was later awarded the Imperial Service Order for his work connected with telephony.

CHAPTER XVIII

FLEMING DISCOVERS THE THERMIONIC VALVE; DE FOREST ADDS THE THIRD ELECTRODE

IT cannot be claimed that wireless, as perfected and established by Marconi, had any popular appeal. The public were at first duly impressed, but after the usual "nine days' wonder" the new marvel was taken for granted, and to a large extent became a part of the daily life of all civilized countries. As a commercial proposition its permanent success seemed assured, and no one would have dared to predict for it any other future. The discovery of the thermionic valve in 1904, however, was destined to make revolutionary changes, not only in introducing an entirely new system of transmission and reception, but also in subsequently making possible radio-telephony and broadcasting as enjoyed to-day by millions of listeners. This discovery was due to John Ambrose Fleming (*b*, Plate XIX), who was born at Lancaster on 29th November, 1849. Fleming was educated at University College and at St. John's College, Cambridge. In 1881 he was appointed Professor of Mathematics and Physics at University College, Nottingham, and in 1885 became Professor of Electrical Engineering at the University of London.

The thermionic valve, sometimes called the electron valve because its working principle is based on the electron, is one of the most wonderful inventions of recent years, and its introduction illustrates the value of detailed observation of trifling phenomena. The valve is deservedly known as "the modern Aladdin's lamp", for the wonders that Aladdin was able to conjure up with the aid of his old lamp are surpassed by the valve, which brings to its owner powers so amazing that even the highly imaginative author of *A Thousand and One Nights* never dreamed of them!

Early in 1882 Fleming was appointed electrical adviser to the Edison Electric Company of London, and in this capacity was brought into close touch with the many problems of the electric lamp. He began to study the physical phenomena with all the scientific means at his disposal. He noticed that the filaments broke easily at the slightest shock, and that when the lamps burned out the glass bulbs became so blackened that the amount of light was considerably diminished.

II

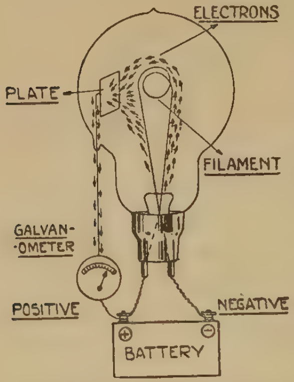


Fig. 36—The Edison effect

This marked discoloration of the glass was also noticed (in 1883) by Edison, who determined to investigate it, although it seemed almost too trifling a matter to call for serious notice. But in science it is the trifles that count, and the little things of to-day often develop into the great things of to-morrow. Edison noticed that in many burned-out lamps there was a line of glass that was not discoloured as was the remainder of the globe. It was as though someone had taken a smoked glass, drawn a finger down it, and left a perfectly clean line behind. Lamps with these strange sharply defined clean spaces were covered elsewhere with a deposit of carbon or metal, the clean line being immediately in the plane of the carbon horseshoe filament and on the side of the loop opposite to the burnt-out point of the filament.

It was obvious that the unbroken part of the filament acted as a screen to that particular line of clear glass, and that the discharge from the overheated point on the filament bombarded the remainder of the bulb with molecules of carbon or vaporized metal, shot out in straight lines. To investigate this action Edison fixed a small metal plate inside the globe. This plate was suspended near the filament, but insulated from it. He was surprised to notice that when the plate was connected to the positive terminal of a battery an electric current passed along the wire from the plate, although there was no metallic connection between the filament and the plate. The passing of the current was clearly indicated by a galvanometer connected between the plate and the battery (Fig. 36). In puzzling over this remarkable effect, Edison came to the conclusion that the current must leap across the gap between the filament and the plate.[1]

Continuing his experiments, he noticed that the current would not leap the gap when the negative terminal was connected to the plate. No matter how strong the battery current, the galvanometer showed that not even the minutest current passed when the connection was made in this way (Fig. 37).

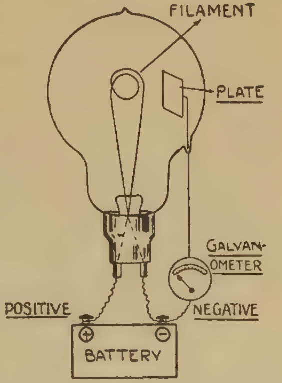


FIG. 37

No current passes between filament and plate when negative terminal is connected to plate.

III

In studying static electricity we learn that "like repels like" and that "unlikes attract each other". This applies also to electrons, and one negatively charged electron repels another similarly charged. On the other hand, a negatively charged electron is attracted by another electron carrying a positive charge. In electrical conductors there are always electrons that are only loosely attached to any of the atoms of which the conducting substance is composed. These are called "free electrons", and, as their name implies, they move about in all directions between the atoms of the conductor. When the conductor forms part of an electrical circuit, however, many of these free electrons are pushed along, as it were, by the electric current, and are made to flow in one direction. It has been found that if the conducting substance is heated, the movements of these free electrons become even more pronounced. If the substance be made very hot, the electrons fly off from the conducting body and attach themselves to other near-by bodies.

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[1] These experiments were made in 1883. See *Engineering*, 12th December, 1884, p. 553.

WORKING
COL

Although Edison was not aware of these facts when he made his discovery, they explain exactly what was taking place between the filament and the positively charged plate. When the filament was heated, a stream of electrons flew off and attached themselves to the plate. They were encouraged to do this because the plate was charged with positive electricity and the electrons in the filament were all negative. Arrived at the plate, they continued their course to the positive terminal of the battery, and in passing through the galvanometer caused it to register their passage. When the plate was connected to the negative terminal of the battery it became charged with negative electrons. The electrons of the filament, being also negative, did not leap the gap between the filament and the plate.

Desiring to perfect his incandescent electric lamp, Edison did not immediately pursue his discovery of the peculiar action, which became known as the " Edison effect ". That he realized its importance, however, is demonstrated by the fact that he took out a patent protecting the discovery.[1] The scientific vision of this remarkable inventor is made clear when we find that his patent specification illustrates a suggested means of wireless communication and includes diagrams of " receiving wires " that are not unlike a present-day aerial.

The idea of the evaporation of electrons from hot bodies was not completely established until 1912. From this theory is drawn the important conclusion that while electronic energy freely leaves the surface of a hot metal, it does not leave the surface of a metal that is cold ! [2] It is for this reason that the electrons cannot leap from the plate to the filament, for the plate is a cold metal from which the free electrons cannot escape.

As we have seen, the plate in Edison's modified carbon lamp attracts negative electrons but repels the positively electrified particles. If we place the lamp in the circuit of an alternating current, it is clear that only the negative electrons will leap from the filament to the plate, the positive electrons being repelled by the plate. Thus only half the alternating current will pass through the circuit. The electrons of which that half is composed will be travelling in one direction only, from filament to plate, thus forming a direct current.

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[1] U.S. Patent No. 307031 (15th November, 1883). The patent was subsequently acquired by the Marconi Company.

[2] By " cold " is meant any metal below a dull-red glow.

IV

Fleming, in London, also was working on the question of the blackening of the inside of the lamps, and (in 1883) he published the result of his researches in a paper on *Molecular Radiation in Incandescent Lamps*. This was followed (in 1885) by another paper, embodying his further researches on *Molecular Shadows in Incandescent Lamps*.[1]

In October, 1884, Sir William Preece, having obtained from Edison some of his electric lamps with metal plates sealed inside them, turned his attention to an investigation of the phenomena of the Edison effect. He came to the conclusion that this effect was connected with the projection of carbon molecules from the filament in straight lines, and there he let the matter rest, just as Edison had done, neither satisfactorily explaining the phenomenon nor seeking to apply it in any way. For the time being, the Edison effect remained a peculiar property of the incandescent lamp, and nothing more.

In 1888 Fleming had some special lamps made at the Edison and Swan lamp works. Some were strangely shaped, with long glass tubes springing from the sides; others had tubes shaped like the letter "L". The filaments were of carbon, bent in the shape of a horseshoe, and within the bulbs, or in the side tubes, metal plates were fixed. With these lamps he conducted many tests of a highly technical nature, which were fully described in various scientific papers to the Royal Society and the Physical Society. He confirmed Sir William Preece's observations that the molecules discharged from the incandescent filament could not pass around a right-angle bend, and doubly confirmed the original discovery that the molecules travelled in straight lines.[2]

Fleming next enclosed the negative leg of the carbon filament in a glass tube, and found that the bombardment of electrified particles was completely stopped. By altering the position of the metal plates, he learned that he could vary the intensity of the bombardment. At last he tried placing a metal cylinder around the negative leg of the filament, without touching it (Fig. 38). The mirror galvanometer that was being used to detect the currents indicated a strong current, from which it was plain that the metal cylinder enclosing the negative filament received electric particles discharged from the filament.[1]

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[1] *Proceedings*, Physical Society, vol. v, p. 283 (1883), and vol. vii, p. 178 (1885).

[2] *Proceedings*, Royal Society, vol. xlvii, p. 118 (1890).

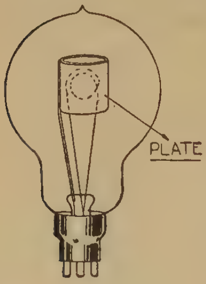

FIG. 38—FLEMING'S CYLINDRICAL PLATE AROUND THE FILAMENT

V

In 1899 Fleming was appointed electrical adviser to Marconi's Wireless Telegraph Company, and in this capacity assisted in solving the technical problem of equipping the wireless station at Poldhu.

We have already described how Marconi improved on the coherer as a receiver by inventing the magnetic detector. Fleming realized that if the alternating current could be rectified or converted into direct current, it would be possible to use the mirror galvanometer of Kelvin to register oscillations that were possibly too weak for known receivers to detect. He experimented with many of the rectifiers then in use, including a rectifier made of plates of aluminium and graphite immersed in a solution of certain salts. The current is able to pass freely from the graphite to the aluminium, but when the polarity is reversed and attempts are made to make the current flow from the aluminium to the graphite, a deposit is formed on the aluminium, and this effectively stops it from flowing. While this rectifier acted well enough for certain purposes when the frequency of the currents was low, it was found to be useless for practical purposes. With a low-frequency current the electric impulses, reversing slowly, give time for the deposits to form on the aluminium plates. Wireless oscillations, coming at the rate of hundreds of thousands or millions per second, were so rapid, however, that they gave no time to create the deposits.

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[1] Fleming also experimented with electric arcs in the open air, and he found that the same phenomenon existed. In 1889 he published the result of these experiments in a paper, *Electrical Discharge between Electrodes at Different Temperatures in Air and High Vacua.*

Finding that these chemical rectifiers were not suitable for use with high-frequency currents, Fleming sought something that would operate more rapidly as a rectifier. He was pondering on the difficulties of the problem when his thoughts recurred to his experiments in connection with the Edison effect, and he determined to see if this could not be made to serve the purpose.

" I went to a cabinet and brought out the same lamps that I had used in my previous investigations ", he has told us. " My assistant helped me to construct an oscillatory circuit with two Leyden jars, a wired wooden frame, and an induction coil. We then made another circuit, in which was inserted one of the lamps and a galvanometer, afterwards tuning it to the same frequency as the first circuit.

" It was about five o'clock in the evening when the apparatus was completed. I was, of course, most anxious to try the experiment without further loss of time. We set the two circuits some distance apart in the laboratory, and I started the oscillations in the primary circuit. To my delight I saw that the needle of the galvanometer indicated a steady direct current passing through and found that we had in this peculiar kind of electric lamp a solution of the problem of rectifying high-frequency wireless currents. The missing link in wireless was found—and it was an electric lamp.

" I saw at once that the metal plate should be replaced by a metal cylinder enclosing the whole filament, so as to collect all the electrons projecting from it. I accordingly had many carbon filament lamps made with such metal cylinders, and used them for rectifying the high-frequency currents of wireless telegraphy.

" This instrument I named an ' oscillation valve ', and it was found to be of value in wireless telegraphy. The mirror galvanometer that I used was replaced by an ordinary telephone—a replacement that could be made with advantage in those days, when the spark system of wireless telegraphy was employed. In this form my valve was somewhat extensively used by Marconi's Telegraph Company as a detector of wireless waves." [1]

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[1] Fleming applied for a patent in Great Britain on 16th November, 1904, and this patent (No. 24850) was subsequently acquired by the Marconi Company. (The U.S. Patent No. is 803684, 19th April, 1905.)

VI

The Fleming valve was introduced in 1904, and was used as a detector or rectifier of radio oscillations. Its sensitivity was equal to that of a carborundum-steel rectifier, but it did not come into general use, probably because of its comparatively high initial and maintenance cost. In 1907, however, it was greatly improved by Dr. Lee de Forest (*a*, Plate XXII), who conceived the idea of introducing into it a third element, in addition to the filament and cylindrical plate, with the result that it became possible to amplify received signals to a very considerable extent.[1]

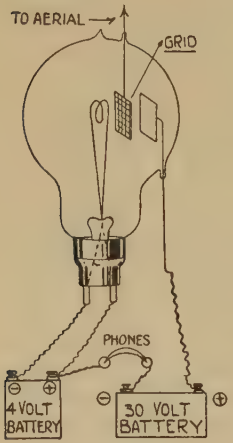

FIG. 39

THE THIRD ELECTRODE

De Forest's third element takes the form of a perforated metal plate, or "grid", supported by a separate connecting wire and fused through the glass of the bulb (Fig. 39). As the grid is inserted between the plate and the filament, negative electrons from the filament must first pass through its meshes before reaching the plate. Bearing in mind that "unlikes attract" and "like repels like", it is not difficult to understand that if the grid is negatively charged it will tend to drive back the negative electrons to the filament. On the other hand, if the grid be given a positive charge, it will assist matters and add its attraction to that of the positively charged plate.

Oscillations received from the transmitting station by the aerial are composed of alternating currents, half positive and half negative. When they influence the grid, which is connected to the aerial, they affect the degree of strength of the negative charge it carries. Thus, when the negative half of the incoming oscillation reaches the grid, it increases the negative charge of the grid and so causes the latter to repel, to a greater extent, the electrons from the filament. When the positive half of the aerial current influences the grid, the flow of electrons to the plate is assisted. In this way the flow of electrons is controlled by the incoming oscillations, which alternately weaken and strengthen the stream from the filament to the plate.

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[1] He applied for a patent (U.S. No. 824637, British Patent No. 5258, 18th January, 1906) for the use of a "B" battery with a diode, and in the following October applied for another patent (U.S. No. 841387) on a triode "for amplifying feeble electrical currents". This invention made the first use of a metal filament.

A comparison may be made between the three-electrode valve, or " triode " as it is called, and a machine gun (the filament) that is bombarding a target (the plate) with bullets (the electrons). The grid, acting as a spasmodic shield between machine gun and target, resembles a Venetian blind that has its laths alternately opened and closed by the presence or absence of an impulse from the aerial. When the positive half of the aerial current influences the grid, the laths are opened and the negative electrons are allowed free access to the target. When the negative half of the impulse influences the grid, the laths are closed, the plate is screened from the filament, and the stream of negative electrons is thus completely cut off.

Every time the grid allows the electrons to pass from the filament to the plate a current is produced in the plate circuit, which impulse is converted into sound waves by a telephone ear-piece connected in the circuit. These impulses are of very much greater intensity than is the original impulse from the aerial, because of the heavy voltage[1] maintained in the local circuit. The valve may be said to resemble the trigger of a rifle, which, by slight pressure of the finger of the marksman, is made to release tremendous energy.

This improved form of three-electrode valve was named " audion " and because, in addition to its property as a rectifier, it may also be used for magnifying changes of electrical potential, it is sometimes called the " amplifying valve ". In America it is known also by the names of " vacuum tube ", " bulb ", " pliotron ", and " radiotron ". It was the subject of U.S. Patent No. 879532 and B. Patent No. 1427/08.[2]

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[1] Generally from 30 to 90 volts.

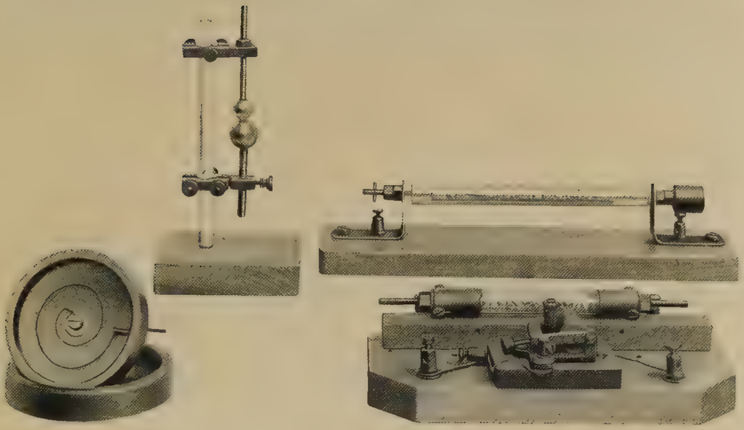
[2] It is a remarkable fact that, when the first renewal of this British patent became due in 1911–12, the fee was not forthcoming and the patent lapsed! The Marconi Company owned Fleming's diode patent, however, and controlled the situation until 1918, when they were unable to secure an extension. In this connection it is interesting to record that, according to a report of the United States Federal Trade Commission, the Radio Corporation of America received orders for 2,931,262 triodes in the first nine months of 1923!

In one of his earlier patents (about 1904) De Forest claimed to have forestalled Professor Fleming, and extensive litigation ensued between the two parties before their respective rights to priority could be determined. In the end the American Courts held that De Forest's patents were intended to protect a device in which the detecting action took place by a process depending upon the conduction of an electric current through a gas-filled bulb by the effect of heat, whereas in Fleming's valve the action was entirely different—namely, a discharge of electricity (by means of the electron-flow between the filament and plate) through what was practically a perfect vacuum. Without actually stating that the De Forest patent was invalid because the description given in his specification was not sufficiently full and clear, the Courts hinted that this was so, and gave judgment in Fleming's favour. Later, the U.S. Circuit Court of Appeals (on 9th May, 1917) held that " the Fleming valve as a detector confessedly, and the actual commercial audion, consist essentially in the utilization by visible and tangible means of what has long been known as the ' Edison effect '. . . . Utilization of the Edison effect does not mean that the use of Edison's apparatus or any modification thereof as a detector was easy or simple. The admitted fact that years passed and detectors of various kinds, from the coherer to the crystal, acquired vogue before anyone thought of using Edison's curiosity of electricity for the discovery or translation of Hertzian waves is proof enough on this point. . . . Fleming was the first to disclose an apparatus for this purpose. . . . [Edison's] disclosures remained (as far as we can discover from the record) a laboratory problem until Fleming applied it to a new and very practical field of usefulness ".

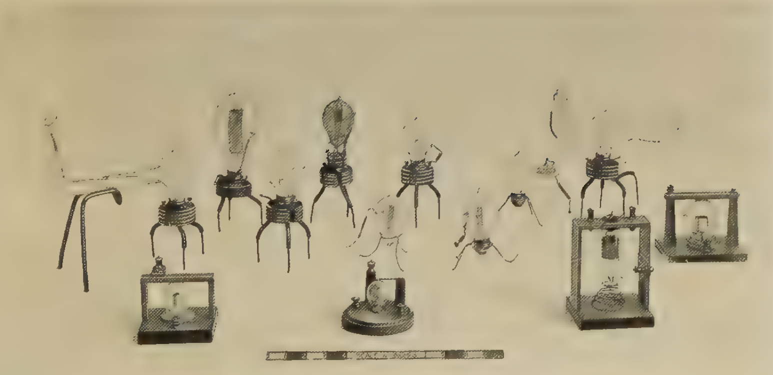
VII

Meanwhile De Forest had added a power battery to the plate circuit, so as to increase the signal strength ; and later he added the third electrode or grid, as has already been explained.

Notwithstanding these considerable and distinct improvements, in view of the decision previously referred to, the Courts held that both these modifications were merely improve-



LODGE'S SPRING COHERER (1894), SPARK-GAP COHERER (1889) AND (RIGHT) TWO BRANLY-LODGE COHERERS (1894)



FLEMING'S ORIGINAL OSCILLATION VALVES (1889-1904)

ments upon Fleming's master patent, and could therefore only be made and held under licence from him.

It is interesting to learn that De Forest, the inventor of the " audion ", commenced his scientific experiments in a room at Chicago for which he paid 10s. per week, and there, as a struggling scientist, he made his great discovery.

> " In that room ", he says, " was born the tiny glass baby that was destined to rule the world of electrical communication—the present transmitter of news and music and the future bringer of untold happiness. Unfortunately, a great fire completely gutted the Parker Buildings in January, 1908, wiping out of existence my note-books and many precious samples of the earliest audion bulbs. These would have to-day shown the history of its evolution in a most interesting way. The memory of that early struggling period still lives—a pleasant memory, no doubt, shared to-day by many who, in one way or another, contributed to the development of the art of radio."

De Forest at first thought that his discovery was only a strange phenomenon, and it was not until later that he realized its importance. He has stated that his discovery was made one night in 1900, when he was experimenting with a new detector. In those days wireless signals were few and far between, and he had to use a small transmitting set in order to be sure of receiving signals. He had installed this transmitting apparatus in the room in which he was working, operating it by means of a string, with the sparking coil in a cupboard about 10 ft. away. He was surprised to notice that when the coil sparked there was a decided change in the light given out by the incandescent mantle that illuminated the room. When the coil was sparking, the light decreased very materially ; as soon as the sparking ceased, the light at once resumed its normal brilliance. De Forest was greatly impressed by this phenomenon, and his interest was so aroused by the peculiar set of facts described that he commenced a series of experiments with the incandescent burner. As a result, he came to the conclusion that " heated gas molecules are sensitive to high-frequency electrical oscillations ".

Having investigated the matter so far, he shelved it for the time being and engaged in other experimental work. Three years later, however, he returned to the subject and commenced a series of extensive experiments, using various types of Bunsen burners. As a result of these experiments, he decided that a flame can be used to detect electric waves, and a flame detector was subsequently used for receiving wireless signals from ships in New York harbour. This type of detector required a large supply of gas, however, and there were many other difficulties in the way of making its use commercially possible.

In his next experiment, De Forest tells us, he employed heated gas, using an incandescent filament enclosed in a glass bulb, and this was the foundation of his three-electrode vacuum tube. He first used a plate consisting of a simple band of tin-foil wrapped around the outside of the bulb. "Then I experimented with two plates—the anode and the control—one on each side of the filament. Finally I tried with the third electrode in the form of a grid, or a perforated plate located between the filament and anode."

> "Little did De Forest imagine", says Professor Howe, "that when he placed a control electrode on the outside of the bulb . . . he was making the most important step in the whole history of radio-telegraphy, but that such was the case no one can now have the slightest doubt."[1]

VIII

"The subjects of wireless and broadcasting, after so many years of what might be called pioneer effort, are close to my heart", said De Forest, when giving an account of his early struggles. "It is not often the happy lot of a prophet to witness within a few years, or even in his lifetime, a full and sudden fulfilment of his prophecies, made before a world of indifference, a world of sceptics.

"Yet in the world of wireless our dreams have come true. Like a tidal wave, the attitude of press and public, of Government officials and trust directorates, towards broadcasting, and even towards the wireless telephone itself, mounted within a few months to a magnitude of interest. This is certainly heart-warming to those who have spent so many years in what appeared, in those early days, to be fruitless effort—the transmission of the news and music by wireless is by no means new.

"It was in the summer of 1907 that I had the pleasure and the thrill of first sending out music such as that being now daily broadcast. This was from a little laboratory in which I was at work in the old Parker Building, corner of 19th Street and Fourth Avenue,

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[1] *Marconi Year Book*, 1921.

New York City—upon the topmost floor; from my roof an aerial was stretched between the two flag-poles.

" It was in testing out some twenty small telephone transmitters for installation on Admiral Evans's battleships and destroyers, prior to their historic round-the-world cruise, that the phonograph was first used to actuate their microphones. During those busy nights and days, the ether around New York was kept thoroughly agitated with music from *Il Trovatore*, and more than one ship's operator working with his (then new) carborundum crystal detector had sudden doubts as to his sanity or sobriety, when above the rattle of the 60-cycle spark he heard, distinct and clear, real music or human voices ! "

IX

The valve has also numerous other applications, as is well known. It may, for instance, be used as telephone relay, and in this connection is extensively employed in America. Another development is its application to the reproduction of synthetic music, the first demonstration of which, given before the New York Electrical Society in 1915, proved to be of great interest both to musicians and scientists. The valve is the most important element in the invention of the talking or " Phonofilm ". With this apparatus sound waves of the cinema actor's voice are reproduced in the form of bands of light on the film. The sounds are picked up by a sensitive microphone and transmitted to the valve that controls a lamp developing a powerful violet light. The strength of this violet light varies according to the strength of the voice-current from the microphone, and so causes records of varying intensity to be photographed in the margin of the film, alongside the picture. When a " talking film " is being shown, the process is reversed, and the light bands in the margin are converted again into sound waves, enabling the original speech to be reproduced.

Between 1904 and 1912 there were filed no less than twenty patents in which the valve played a prominent part. To-day over 100 patents have been granted in this same connection, and the number is rapidly growing. Practically every one of these patents is dependent upon the three-electrode valve.

It may here be mentioned that De Forest invented a method of wireless communication that was successfully used in the Russo-Japanese War, and which, it was claimed, gave the best record for accurate service during the naval manœuvres with the American Fleet in 1902. The most interesting part of this system was the "responder", which took the place of the coherer of Marconi's method and depended for its action on the electrolytic principle. The receiver included also a variable inductance and adjustable condenser for tuning, a potentiometer, fixed condenser, and, of course, a telephone receiver. The transmitter used an alternating-current dynamo in place of coils or interrupters with a step-up transformer to increase the voltage. The current was discharged across a gap in which was interposed a detached conductor. The discharging electrodes and interposed member, of the same size and shape, were discs of metal $\frac{1}{4}$ in. in thickness. The spark-gaps were $\frac{1}{64}$ in., and "fat" sparks were obtained, producing the best results. A speed of over forty-eight words a minute was claimed.

In December, 1903, De Forest made a series of successful transmissions between Holyhead and Howth, a distance of 65 miles, signals passing at a speed of between twenty and thirty words a minute.

It may be of interest to note here that it was De Forest who invented the grid-leak, which was the subject of U.S. Patent No. 1377405 and B. Patent No. 100358.

X

Before describing further developments of the valve it may be of interest to mention something that is not generally known. This is the fact that an Austrian, Von Lieben, appears to have patented a similar invention to De Forest's "audion" at a date nearly four months earlier. Von Lieben, whose patent was filed on 4th March, 1906, in the German Imperial Patent Office, had been working for many years on cathode and other types of ray-emitting tubes, originally produced and modified by Crookes, J. J. Thomson, and others in the early 'nineties.

When making experiments with cathode rays in 1895 Röntgen noticed the phosphorescence of substances near his apparatus and traced it to rays produced in the cathode tube that he used. These rays were named by him "X-rays". They affected a photographic plate, and with them he was able to photograph a door-key through a leather case. The earlier tubes used for the production of X-rays were evacuated and contained two electrodes. The anode was a flat plate, the centre of which was also the centre of curvature of the semi-spherical surface of the plate that acted as cathode, these two electrodes being connected to the terminals of a high-frequency source such as the induction coil.

At first the degree of exhaustion of the cathode tubes used was comparatively low, and the cathode rays, being a stream of the small negatively charged particles known to-day as electrons, were easily deflected by a magnet. Later a much higher degree of exhaustion was adopted, which had the result of increasing the speed of emission of the cathode stream. This increase in the speed of the emission led to an increase in the hardness of the X-rays excited by it, with a correspondingly greater power of penetration. Unlike the cathode rays, X-rays were not deflected by the application of a magnetic field, and were found by Marx to have the same speed as light.

Coolidge discovered that a stream of electrons could be obtained when the cathode was heated by a separate electrical circuit, and that X-rays could be obtained by bombarding the anode with this stream. His tube was an improvement on the old type because of its economy and the very definite control that it allowed over the X-rays produced. The penetrating power of the rays was found to depend on the voltage applied to the tube, and the density of the stream of electrons upon the temperature of the cathode.

The influence of these ideas is seen in the three-electrode tube of Von Lieben, who adopted from Wehnelt the use of a metallic oxide surface for the cathode, certain of these oxides having been found to produce very high electron emission when heated in a vacuum. He also adopted the spherical surface of Röntgen as the correct shape for the cathode, and used for the third electrode a tubular-shaped grid. This grid was controlled from an external circuit either electromagnetically or electrostatically. This grid member was so placed that the beam of negative electrons from the cathode passed through it on the way to the anode, which attracted the electrons in virtue of its positive charge.

De Forest used magnetic and electrostatic means of controlling the third electrode as described in his original patent. In one case he placed a wire-wound horseshoe magnet in such a position that it would influence the flow of electrons in the tube. The variations of the electrical conditions on the grid, or control electrode, produced corresponding changes in the circuit of which the anode formed a part, this being the essential feature of the modern wireless valve. When the original De Forest patent was filed twenty years ago, little was known of the true nature of the processes inside the tube. De Forest himself admitted that he could not explain the character of the phenomenon he had discovered and for which he had been granted patents.

In Von Lieben's original specification it is clearly stated that the invention relates to a device for releasing energy in a relay manner, and it definitely mentions telephone and telegraph relay purposes as its object, as well as the carrying of wireless telephone messages, the amplifying and building up of speech and music transmission, and telephotography.

Von Lieben also states that he desires to utilize a vacuum in which an electronic stream will be emitted in a circuit with a potential of 200 volts. This clearly outlines the degree of vacuum in use to-day in the modern radio receiving tube.

In the circuit shown by Von Lieben a " B " battery is provided and a " C " battery in the external circuits is connected to the tube electrodes. He also takes up the proposition of transmission and mentions the use of a microphone in the grid circuit, even showing its position.

Another point is that the external circuit of the collector electrode shows the positive terminal of the " B " battery connected to the plate, and that a means of feed-back is shown in " apparatus A ", though not claimed in the patent specifications.

XI

So far we have dealt only with the valve as a receiver, and the discovery that the device could also be made to serve as a generator of continuous oscillations was of the utmost importance to the progress of wireless. Not only did it provide a more compact and economical form of high-frequency generator than any then known for the transmission of continuous-wave and tonic-train signals, but it opened up new fields of possibility in the shape of portable and comparatively inexpensive telephone transmitters. This application proved of particular value in making it possible to design wireless-telephony and long-range C.W. signalling sets for use in aircraft, where the question of weight is of primary importance.

Apart from the increased demand thus created for valves for transmission work, it must also be remembered that, with the extension of the use of C.W. signalling, they found a further wide sphere of usefulness in heterodyne reception. Having regard to all these facts, it is not, perhaps, surprising to find inventors treading very closely upon each other's heels in the struggle to claim priority for so vital an improvement.

The first mention of a valve capable of producing oscillations is apparently made in a patent, No. 13636, filed on 12th June, 1913, in the name of the Marconi Company and Charles S. Franklin. The inventors, in their specification, state that they make "the circuit in which the magnified oscillations occur (plate circuit) react on the circuit in which the oscillations to be magnified occur (grid circuit) by coupling these circuits, either electrostatically or electromagnetically, to a certain degree". It is further pointed out that by so coupling the circuits the system may be caused to produce continuous oscillations, and that this effect may be utilized to receive C.W. signals by the interference method (heterodyne). In a somewhat later patent, filed on 9th December, 1913, by the Marconi Company and Henry J. Round, a specific claim is made to a valve in which the plate circuit is tuned to a frequency slightly different from that of the received waves, in order to secure heterodyne reception of continuous-wave signals by the use of a single valve.

This leads us to the consideration of one of the most important applications of the valve, that discovered by Major E. H. Armstrong. Late in 1914 he filed a patent application claiming under the International Convention a priority date corresponding to that on which he first filed the corresponding specification in America, namely, 18th December, 1913.

In this application Armstrong claims a thermionic receiver of wireless signals in which the receiving circuit (grid) is linked to the detector circuit (plate) by a combined electrostatic and inductive coupling, in order to facilitate the transfer of the energy of the high-frequency oscillations from the plate or wing circuit to the grid circuit.

In the course of this specification Armstrong makes reference to a previous American patent application, dated 29th October, 1913, in which a claim is made to the use of an audion, or three-electrode valve, for both amplifying and detecting wireless signals.[1]

Armstrong's principle, known as "regeneration", is made use of in several forms of circuit, chief among which are the Armstrong circuit and the Franklin circuit. It is also sometimes referred to as the "feed-back circuit", the Ultra-magnifier, and the Ultra-audion. It exists in many forms, some of which are simple in design and more easily operated in actual practice, whilst others are exceedingly complicated and call for high technical skill.

The effect of regeneration is to supply energy to an incoming oscillation, thus enabling it to build up oscillations in the valve circuit. These oscillations are maintained indefinitely, and they more easily overcome the resistance of the circuit. All conductors—and especially fine wires—oppose the passage of an electric current to a certain degree, and in so doing consume energy as the current flows. In this a circuit resembles a pipe which, by friction, opposes the passage of flowing water. By allowing the oscillation to be considerably strengthened, regeneration can be made to balance resistance, which can only be reduced by this means. It must not be imagined that resistance can with advantage be reduced to below zero by regeneration, however, for if that stage is reached, a local oscillation is started, which itself becomes built up and, emanating from the aerial as a wave with a frequency of that of the grid circuit, does in fact cause the receiving set to act as a transmitter of "oscillations". Regenerative sets are, naturally, very sensitive, and the least possible disturbance in the balance of the circuit will be sufficient to cause them to oscillate.

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[1] A British application was, in fact, made to cover this earlier American patent as late as July, 1920. For this application the inventor claims the early priority date of 29th October, 1913, under the provisions of certain War Emergency legislation framed in order to meet the case of inventors who found themselves unable by reasons arising from the state of war to attend to the formalities of filing patents, etc., in strict accordance with the statutory dates.

Regenerative oscillation is one of the most effective methods of radio reception, and has given some amazing results. Employing three valves, the Armstrong regenerative circuit has given results that could only be obtained by using nine valves with ordinary circuits. Demonstrating his circuit before the American Institute of Radio Engineers, Major Armstrong filled a large auditorium with music from the broadcasting station WJZ 15 miles away, using only a small frame aerial some 3 ft. in diameter.

XII

Another important application of the valve is that called "Heterodyne", from the Greek *heteros*, meaning "other", and *dynamis*, "force". This method, a variation of which is called "beat reception", is chiefly used for continuous or undamped waves. It includes within the scope of its meaning any method of reception that combines a local oscillation with the aerial oscillation (Fig. 40).

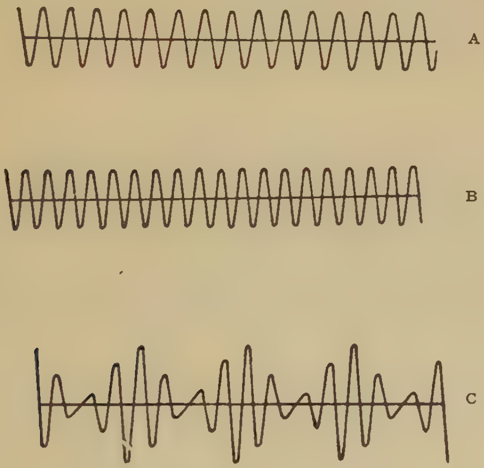

FIG. 40—BEAT RECEPTION

A. Oscillations received from aerial
B. Oscillations in the local circuit of a slightly greater frequency than those in A.
C. The combined oscillations of A and B give a regular and distinctive beat.

The principle (suggested in 1902 and applied in 1907 by R. A. Fessenden) consists of impressing a local oscillation on the oscillation from the aerial. With ordinary detectors the strength of a received signal depends on the intensity of the oscillation and varies with it, according to the square of the intensity. Thus, if the intensity of an oscillation be halved, the strength of the resulting signal will be reduced to one-quarter. With heterodyne reception, however, the strong local oscillation is impressed upon the weak aerial oscillations, the combined oscillations being passed to the detector, where the increased intensity obtained from the strong local circuit gives a considerable advantage.

If the incoming oscillation is weak very careful adjustment of the tuning circuit is necessary so that the natural oscillation shall exactly synchronize with it. On the other hand, should the incoming oscillation be strong, tuning need not necessarily be so close, for the strong incoming impulse will compel the natural oscillation to synchronize, even if the latter is somewhat out of tune.

XIII

Since the first transmitting valves were made, there has been a continual improvement in design and workmanship. What is of greater importance, however, is the fact that it has been found possible to make large valves capable of radiating great power. For stations communicating on long waves over distances of 3,000 miles or more, generating apparatus of 200–300 kw. is necessary, and until these large valves were invented, a number of small valves was required to give a corresponding output of 200–300 kw. The drawback to the use of a single large transmitting valve is that the plate would be subjected to such a fierce electron bombardment from the large currents employed that it would become excessively heated, and the heat radiated would cause the glass bulb in which the elements are contained to be almost instantaneously fused. A solution to the problem has been found in replacing the glass bulb by a metal case, which is surrounded by a water jacket and so cooled.

During 1922 exceedingly powerful valves were produced. At first a valve giving 5 kw. was made, with plates of

PLATE XXI

IRVING LANGMUIR WITH ' PEA-NUT ' AND 20-K.W. VALVES

D. HOUSEKEEPER WITH 1,000-K.W. VALVE

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molybdenum, allowing the use of high temperatures without impairing the efficiency. Subsequently valves were made[1] having an output of 20 kw. and operated by a current of 15,000 volts on the plate. The filaments were of tungsten and were $\frac{1}{25}$ in. in diameter, requiring about 1 kw. for heating. Tests at Long Island showed that twenty of these high-power valves, each of 20 kw. output and arranged in parallel, were sufficient to transmit good signals to Nauen (Germany) with an aerial current one-half of that used when the Alexanderson high-frequency alternator was employed.

A great advance was made—and at the time of its announcement it was said that a limit in size had been reached—with a 50-kw. valve invented by Dr. Irving Langmuir[2] (*a*, Plate XXI). This type of valve, which has been under development for ten years, was submitted to a test lasting 16 hours, conducted from the powerful station Radio Central at Rocky Point, Long Island. In this test these valves replaced the great Alexanderson alternators. Although the valves could easily have been contained in a suit-case, they transmitted the enormous power as satisfactorily as it was normally transmitted by the costly alternators weighing several tons. Six valves were employed to transmit signals from America to England, the power used being 15,000 volts. The valves worked so well that the operators at the receiving station, who had not been warned of the test, were unable to tell that a change had been made from the usual method of transmission.

Even these 50-kw. valves have now been eclipsed by the construction by Dr. Housekeeper of a valve called the "Magnetron", which has the astonishing output of 1,000 kw. (*b*, Plate XXI).

This valve, which involves the principle of magnetic control proposed by Dr. A. W. Hull, consists essentially of a water-cooled cylindrical anode 30 in. in length and 1¾ in. in diameter. In the axis of the anode is a tungsten filament 0·4 in. in diameter and 22 in. in length. This filament is excited by current of 1,800 amperes at 10,000 cycles, the filament excitation requiring about 20 kw. The magnetic field produced by this large heating current is sufficient to "cut off" the electron current from the cathode to the anode during a portion of each half-cycle of the current passing through the cathode, this action taking the place of that of the grid in the three-electrode tube. The electron current to the cathode is thus interrupted 20,000 times per second. By the use of properly tuned circuits this can be used for the production of high-frequency power radio, or any other purposes. This particular size will supply 1,000 kw. of 20,000 cycle power at efficiency of 70 per cent. operating with an anode voltage of 20,000 volts D.C.

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[1] In the laboratories of the General Electric Company, U.S.A.

[2] Research engineer of the General Electric Company.

In these giant valves the filament was coated—or, to speak more accurately, slightly adulterated—with thorium oxide. The addition of thorium oxide was found to increase the electron emission of the tungsten by 130,000 times, substantially reducing the energy expended in heating the filament and considerably increasing its life.

The fact that metallic oxide shows extreme sensitivity to heat and high cathode emission in a vacuum was developed by Dr. A. Wehnelt,[1] and the process has now passed out of the experimental stage—in fact, the Wehnelt oxide coating as a source of electron emission has withstood the test of science for more than twenty years.

In manufacturing valves that utilize Wehnelt-coated sources of emission, the craftsman makes a compound of strontium and barium oxides with resin, wax, or paraffin, in a soft, doughy solution. This compound is painted on strips of platinum-iridium alloy. As each painted coat dries, it is burned off, and successive coats are applied and burned off until as many as twelve to fifteen layers of oxide are applied, the final piece being used as a vacuum-tube filament. In the larger types of valves, glass tubes electrolytically coated with silver upon which the oxides are deposited are used as sources of emission.

The advantages of the thoriated filament are due to an absorbed film of metallic thorium on the surface of the film, this film consisting of a single layer of atoms. The thorium as fast as it evaporates off the surface is supplied by diffusion from the interior of the filament. In utilizing this effect a

[1] On 15th January, 1904, he obtained a German patent No. 157845.

particularly high degree of vacuum is desirable, or at least the presence of those gases must be avoided that would oxidize, or otherwise combine with the very thin film of thorium. For this purpose the vapours of various reducing materials, such as magnesium, or alkali metals such as potassium substances containing carbon, have been used.

Very successful results have been obtained in adopting this thorium filament in power valves. It is possible not only to cut the energy necessary for filament excitation down to a small fraction of what it now is, but also the life of a cathode can be increased greatly, so that the practical applications of electron valves of large power will certainly not be limited by an unduly short life.

The perfection of the giant valve has made possible transatlantic telephony on a commercial scale, and it is certain that the valve will find new fields of usefulness of even greater importance than the linking up of the Old and the New Worlds. Its success has an immediate and important bearing on electric railway traction and on the problem of direct-current transmission at very high pressures. It is not too much to imagine that the time will come when it will be used to transmit energy by radio. When such a development takes place, power, generated at Niagara Falls, will be available to operate machinery in New York and elsewhere without intermediary cables. Whatever else may be said of these large valves, it is certain that they undoubtedly foreshadow vast changes in the practice of electrical engineering on the largest scale, and they cannot fail also to exercise a considerable influence on other branches of electrical industry.

The researches that culminated in the production of these valves emphasize the supreme importance of not only " industrial research ", to which the authorities in this country seem to prefer to devote their energies, but research in pure physical science. Discoveries in this latter field cannot but be followed by their practical application to industry.

Little did Fleming dream of the vast importance of his discovery of the electron stream of his new detector of wireless signals. Even less did Edison anticipate the stupendous results that were to follow his application of the principles that cause the inside of a carbon lamp to blacken. Some people are inclined to think that in this scientific age we have discovered everything worth discovering, and that there is nothing more to be found. The reverse is the case, however, for there is no end to the hidden mysteries of Nature, which science, by slow and patient steps, continually reveals—the farther we go, the richer are the stores revealed.

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CHAPTER XIX

FESSENDEN, DUDDELL, GOLDSCHMIDT, AND ALEXANDERSON—PIONEERS OF WIRELESS TELEPHONY

OUR story of the pioneers of wireless is now all but told. We have traced the subject, from the earliest times to Marconi's conquest of the Atlantic, by means of the men who have done so much—and for the most part gained so little—to benefit their fellow-creatures. Our story would be incomplete, however, were we to make no mention of the pioneer efforts to perfect wireless telephony—the transmission of speech as distinct from wireless telegraphy, the transmission of the dot-and-dash of the Morse code.

Although wireless telegraphy certainly laid the foundation for the wireless transmission of speech, the problem offered by the latter objective is very different and infinitely more elusive. In order to make this clear it will be necessary to briefly explain the nature of the underlying principles and to recapitulate the problem that the pioneers of wireless telephony had to solve.

In the first place, wireless telephony depended on the invention of some apparatus that would propagate undamped, continuous electric waves at radio-frequency. This has been made possible in modern practice by three separate inventions—the Poulsen arc, the high-frequency alternator, and the thermionic valve.

Professor Hughes discovered that the resistance of a loosely packed conducting material to an electric current varied enormously with the alteration in pressure to which the conducting medium was subjected. He found that sound waves impinging upon the conductor were sufficient to vary the resistance, and consequently the current in the circuit. This discovery forms the basis of the transmitter in the ordinary line-telephone. The voice of the speaker impinges on a diaphragm, behind which carbon granules are loosely packed. These granules are compressed or relaxed in varying degrees, according to the nature of the sound waves that strike the diaphragm. Variations of current in the circuit follow, and cause a corresponding variation of current in the receiver.

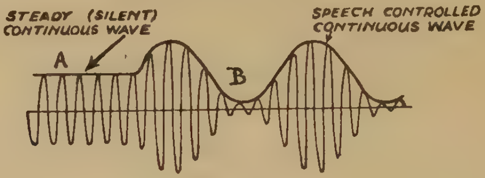
STEADY (SILENT) CONTINUOUS WAVE
A
B
SPEECH CONTROLLED CONTINUOUS WAVE

FIG. 41

A. STEADY WAVES. B. CONTROLLED WAVES.

By means of another diaphragm, the original sound waves are exactly reproduced, and so the listener is able to hear what is being said by the speaker.

As the telephone is sensitive only to variations of current, a current of unvarying intensity will not cause any sound to be heard, except perhaps a faint " click " at the moment of making and breaking the current. In practice, a steady current is generated through the transmitter, but this current is varied in amplitude by the action of the diaphragm, as described above.

Although radio-telephony is carried out on an exactly similar principle, the variations in the current as used in line-telephony are of too low a frequency to cause electromagnetic waves in the ether, nor are they sufficiently powerful.

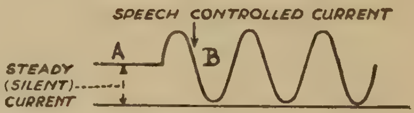

FIG. 42—OUTLINE OF SPEECH CONTROLLED CURRENT AS IT REACHES THE TELEPHONE

To overcome these difficulties a " carrier wave " is employed, formed by the emission of undamped high-frequency oscillations of constant amplitude. As in line-telephony, a transmitter is introduced in the circuit and impresses the variations caused by the voice on the carrier wave. These variations, superimposed on the oscillations of the carrier wave, cause it to fluctuate in strength, according to the sounds transmitted.

As will be seen from Fig. 41, the oscillations are divided into groups, each of which helps to form the outline of the speech-controlled wave. Eliminating the individual oscillations, we get a general change of outline of the speech-controlled current as shown in Fig. 42. The groups persist so long as the sound to be transmitted remains unchanged. For instance, if the operator is singing one sustained note, the record would be as shown in Fig. 43, the regular group-contours persisting as long as the note continues. Should the operator commence speaking, however, the contour of the groups would become irregular, as shown in Fig. 44.

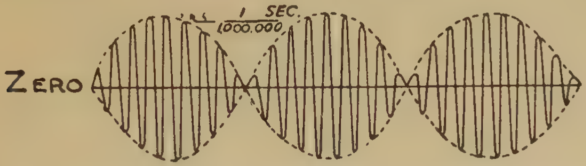

FIG. 43—OSCILLOGRAPH OF WAVES WHEN OPERATOR IS SINGING OR WHISTLING ONE NOTE

Supposing that a singer was broadcasting very softly a note, the pitch of which was "middle C". The strength of the carrier wave would be varied at a constant rate that corresponds to the pitch of that note. Assuming the singer next sings the note with full power, the carrier wave is again varied at exactly the same rate as previously, but it is now strengthened to a greater degree and thus gives the effect of loudness. If, now, the note sung to be an octave higher in the scale, the intervals between the regular group contours would be shortened to a quicker rate—there would be more undulations in a given space of time—the effect being to make the pitch higher. The difference between notes in music

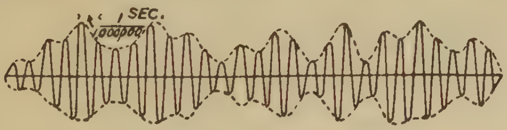

FIG. 44—OPERATOR SPEAKING

[illegible]

and vowels and consonants in speech is reflected in the varying outline, or shape, of the speech-controlled current, which is quite distinct from the rapidity with which the outlines follow each other, or from the degree of their strengthening.

All this was realized by those who attacked the problem, and of these probably Fessenden may be regarded as the pioneer.

II

Reginald Aubrey Fessenden (*b*, Plate XXII) was born on 6th October, 1866, at Milton, Quebec, his father being Rev. E. J. Fessenden. Fessenden was educated at Bishop's College, Port of Quebec, and was principal of the Whitney Institute, Bermuda, 1885–6. He was Inspecting Engineer for the Edison machine works, 1886, and in 1887 became Head Chemist at the Edison Laboratories. Three years later he was appointed Electrician to the Westinghouse Company, where he remained until elected Professor of Electrical Engineering at Purdue University, 1892. The following year he became Professor of Engineering at the University of Pittsburg, where he remained until appointed General Manager of the National Electric Signalling Company in 1902.

It was in 1892 that he first studied Hertzian waves at Purdue University, and from that time to the present his work in connection with wireless has been unceasing. He endeavoured to transmit speech by the old spark-gap method, but soon found it was impossible to do so and recognized that a continuous wave was the first necessity in radio-telephony. In 1898 he set to work to endeavour to produce a continuous wave, first by commutating a continuous current, then by a continuous arc, a high-frequency dynamo, and lastly by an unstable current.

In 1900 he succeeded in first transmitting speech by wireless over a distance of a mile at Cobb Point, Maryland, using a commutator that gave 10,000 cycles per second. The articulation of the transmitted speech was not clear, however, and continuing his experiments he obtained better results, two years later, by the continuous-arc method. Using a frequency of 50,000 cycles per second, he was able to transmit clearly articulated speech for distances up to 12 miles. In

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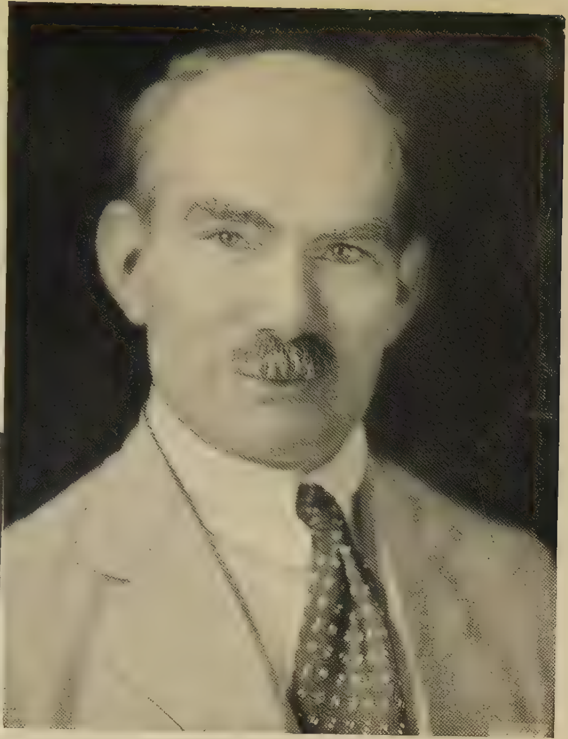

LEE DE FOREST
(b. 1873)

REGINALD AUBREY FESSENDEN
(b. 1866)

1903 he had increased the range up to 25 miles, and carried out public demonstrations at Washington.

In the meantime he developed a high-frequency alternator and finally installed three dynamos at Brant Rock, Mass., two of which operated at 50,000 cycles and a third at 100,000 cycles per second.

Instead of the Branly type coherer, which had to be tapped back every time a signal was received, he invented several devices, the first of which was the ring receiver mounted on a sensitive microphonic contact, followed by the hot-wire barretter and the liquid barretter. He also devised an interesting type of receiver in which a small hot-wire barretter mounted on a small rubber holder fitted inside the ear. Invisible wires ran to the hat-band and down the side of the body, permitting wireless telephone messages to be received by a person walking about in the fields several miles from a station.

In 1906 he transmitted between Brant Rock and Plymouth and relayed conversation over the land lines, successfully demonstrating the possibility of connecting a land telephone line to a wireless telephone station.

> " As it is realized ", he said in a lecture in 1908 before the American Institute of Electrical Engineers, " that the use of wireless telephony would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented, both for the receiving and transmitting ends. These were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock and re-transmitted from there wirelessly by a telephone relay, received wirelessly at Plymouth and there relayed out again on another wire line."

Fessenden also maintained regular wireless conversation between Brant Rock and Jamaica (L.I.), a distance of 200 miles, with articulation that was stated to be clearer than that on the land lines between the two places. In 1907 he invented an apparatus that permitted simultaneous talking and listening.

III

It is interesting to note that Fessenden claims to have been the first to transmit speech across the Atlantic, although this was not an intentional transmission. The incident occurred in November, 1906, when his operators, telephoning between Brant Rock and Plymouth, were overheard on several occasions by operators at Machrihanish, Scotland. They not only identified the voices of the men speaking but sent back several reports giving the exact words of the conversations, which were subsequently verified by the log-books of the station.

As a result of tests made by the Bell Telephone Company, a contract was entered into in 1908 for the construction of wireless installations to work between Boston, New York, Buffalo, and Washington. The contracts were not carried out because the financiers of the Bell Telephone Company decided that the company was expanding too rapidly. In consequence of this revision of policy wireless telephony for commercial use was delayed for about a dozen years.

IV

Fessenden brought out an ingenious method of overcoming cross-talk, the publication of which was at the time of its discovery (1915) forbidden by the Government on account of the war. The method consists of splitting speech into a spectrum band and transmitting each element of the speech spectrum separately, then reassembling the elements at the receiving end. In practice each subscriber would be given a number in the wireless directory, and on turning the indicator to the figures of the call of the person to whom he wished to talk, and throwing the switch, he would find himself in direct communication with the person called.

Incidentally it may be mentioned that Fessenden claims credit for the invention of the radio compass and many other inventions not connected with radio, including the smoke cloud for tanks, the electricity-driven battleship, and the location of enemy artillery by sound ranging. He has recently invented a high-frequency alternator which, although only 6 in. in outside diameter, delivers ¼ h.p. at 50,000 cycles. Television has also occupied his attention, and a short time ago it was announced that he was at work perfecting an apparatus with which

> "it will be possible to point a radio camera connected to an aerial at the steps of the Capitol in Washington, and by so doing enable every

radio subscriber actually to see senators at debate in Congress. Every gesture will be visible and in addition the speech will be heard by means of the radio telephone. With the experimental instrument already constructed, the size of the picture is limited to 4 ft. × 4 ft. on a screen 12 ft. distant or 4 in. × 4 in. on a screen 12 in. distant. The coarse-grainness of the image at a distance of 12 in. corresponds to the 50 dot per inch process plate photo."

V

To return to the wireless telephone, on which others were at work contemporaneously with Fessenden. In 1900 William Duddell, of London, discovered that the "singing arc" emitted continuous oscillations of constant amplitude, and he applied for a patent for his method of generating alternating currents from a direct-current supply with carbon electrodes.[1] He pointed out that the high-frequency oscillations he obtained could "be used with advantage in wireless telegraphy", especially when it was "required to tune the transmitter to syntony".

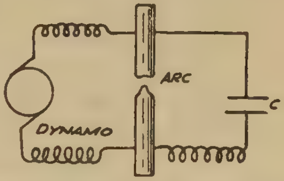

FIG. 45—AN ARC AS A MEANS OF GENERATING CONTINUOUS WAVES

An electric arc consists of two carbon rods close together and connected to a source of electric current. The points of the rods become incandescent and the small space between is filled with glowing carbon vapour. By connecting an arc to a direct-current dynamo on the one hand and to a condenser on the other, the latter becomes charged and discharged, thus alternately lowering and increasing the current through the arc (Fig. 45). This ebb and flow of the current occurs with a frequency that is determined by the natural electrical period of oscillation of the condenser and by the dimensions of a coil of wire that is connected between it and the arc. Its period thus resembles the swinging of a pendulum, which depends on the length of the rod and the position on it of the weight.

Almost everyone has heard the "humming" of the arc lamps used for street lighting. If the frequency does not exceed about 30,000 cycles per second, the arc gives off a musical note, the pitch of which depends on the frequency. Because of this fact this type of arc has been called the "singing" or sometimes the "musical" arc. If the frequency of the vibrations exceeds 30,000, the resulting "sounds" are beyond the range of the human ear.

---

[1] His method was very similar to that patented by Elihu Thomson, of America, in 1892, but Thomson used metal electrodes, which were not enclosed in a gas chamber (U.S. Patent No. 500630).

Duddell's method [1] was the basis of numerous experiments in wireless telephony, carried out by many workers, both in Europe and in America. As the highest frequency obtainable was only about 10,000 per second, however, and as frequencies of a million or over were required, the results were limited until Valdemar Poulsen, of Copenhagen, improved the Duddell arc (in 1903) by placing the electrodes in a chamber containing hydrogen, coal-gas, alcohol vapour, or other gas of high thermal conductive power.[2] He cooled the positive electrode by water and incorporated the magnetic blow-out suggested (in 1892) by Elihu Thomson. This method was eminently successful and is in use for telegraphic transmissions at many stations to-day, notably at Leafield, near Oxford.

Other forms of arc have been tried from time to time by different workers, including Fleming's oil-cooled arcs in series, burning in an atmosphere of vaporized oil and working on a 200-volt direct current. In America, De Forest experimented with an arc similar to that of Poulsen but using alcohol vapour in place of hydrogen. In France, Colin and Jeance's arc consisted of carbon discs working in an atmosphere of acetylene and hydrogen. In Japan a method known as the TYK system was used, in which the arc was struck between electrodes of magnetite and brass. In Berlin, the Wireless Telegraph Company produced high-frequency oscillations (in 1906) by using a number of arcs in series. They overcame the difficulties of high temperatures by water-cooling the positive electrodes, which were constructed in the form of copper tubes to enable this to be done. Even then, however, only small currents could be dealt with.

VI

For many years attempts were made to improve upon the arc by endeavouring to evolve some form of alternator. In this there were many difficulties to be overcome before the exceedingly high frequency necessary could be obtained.

---

[1] British Patent No. 21629.

[2] British Patent No. 15599, U.S. Patent No. 789449.

In 1831 Faraday had shown that when a magnet is moved to or from a wire an electric current is created in the wire. As has already been mentioned, it is this discovery that forms the working principle of the dynamo, which supplies current available for use in electric lighting and power. A dynamo in its simplest form consists of a coil of wire rotating in a magnetic field, caused by utilizing a portion of the current produced by the dynamo itself. The field is concentrated by means of iron cores. As the coil rotates it cuts the " lines of force ", and so a current is induced in the coil. The rotating coil is known as the " armature ".

When the current so induced flows first in one direction and then in the other it is said to be an " alternating current ". The frequency of an alternating current is expressed in " cycles ", and depends upon the number of the electromagnets used and the number of revolutions per second of the spindles on which they are mounted. Assuming that there are 50 poles (i.e. 25 pairs of magnets), and that the spindle makes 6,000 revolutions per minute (or 100 per second), the frequency would be said to be 2,500 cycles per second (25 × 100 = 2,500). Thus in a second of time the current would be reversed 5,000 times.

We have already seen that the required frequencies of the electrical oscillations used in radio are very high. Although at first sight a frequency of 5,000 per second may seem high, it is very much too low to be suitable for the purposes of transmission. Because of the limits of safety in the speed of the revolution of the dynamo spindle,[1] and because of the fact that the size of the spindle limits the number of magnets, it is impossible to increase the frequency of a dynamo indefinitely.

A spindle of 2 ft. diameter, carrying 800 poles and rotating at 50 revolutions per second, will produce an alternating current of a frequency of 20,000 cycles. To be of service for radio purposes this current would require to have a frequency from two to possibly five times as great and to be of very high voltage. If this very high frequency could be obtained, condensers, spark-gap, and arc could then be eliminated, for the necessary frequency would be obtained direct and without their aid. One terminal of the alternator could be connected directly to the aerial, the other being connected to earth.

---

[1] A dynamo spindle, which is really a wheel, cannot be safely rotated if its peripheral speed be greater than 250 to 400 ft. per second.

VII

The importance of some such form of high-frequency alternator was realized many years ago, and several workers gave the subject considerable study, realizing that the possibility of radio-telephony depended on a solution of the problem. Although experiments were carried out over many years, it was not until just before the outbreak of the war that the alternator became a commercial proposition.

One of the most ingenious solutions to the problem is the rotating-field alternator of Dr. Goldschmidt, in which low-frequency current is transformed so that its frequency is increased as desired. This is accomplished by using two types of coil—the " stator ", or fixed coil, and the " rotor ", or rotating coil. By exciting the stator with a direct current, it is surrounded by a magnetic field. The rotor coil moves in this magnetic field, causing an alternating current to be induced in itself. Around the rotor is induced also a corresponding alternating magnetic field, which pulsates but is stationary in direction as regards the rotor, although moving with it.

A magnetic force possesses the property of remaining invariable or constant in direction, although it may change in intensity. On the other hand, it may remain constant in strength and yet change in direction. It is also well known that if two magnetic forces are superimposed at any point, they combine and become a single force.

The rotor coil, with its induced alternating current, rotating within the stator, produces a pulsating magnetic field. This in turn is composed of two magnetic fields of constant intensity which are themselves moving in opposite directions with the same velocity as that with which the rotor is rotating. One of these magnetic fields is carried back by virtue of its own rotation, and as the speed is identical with the forward motion of the rotor, it is (to all intents and purposes) in a fixed position as regards the stator.

The second field moves with double the velocity of the rotor, cutting through the stator and inducing in it a current of double the frequency of the rotor current.

Thus a direct current in the stator induces an alternating current, having a frequency of, say, 10,000 cycles, in the rotor. This current will induce a current with a frequency of 20,000 cycles back to the stator, this latter current in turn producing a pulsating magnetic field composed of two oppositely rotating fields. One of these fields has a velocity identical with the rotor velocity, and the other a velocity three times as great. The effect is to produce alternating currents in the rotor circuit with frequencies of 10,000 and 30,000 cycles respectively, and to produce a current in the stator with a frequency of 40,000 cycles. The frequency of this latter current may be continually multiplied, and current of the desired frequency drawn off by a suitably tuned circuit connected to the stator, currents of lower frequencies being taken up by condensers.

One of the earliest long-distance stations to use the Goldschmidt alternator for transatlantic service was Hanover (Germany), working direct with Tuckerton (New Jersey, U.S.A.). The station would have been of considerable use to Germany during the war, but the terrific speeds of rotation proved to be a strain that the alternators could not stand, and they failed just about the time war broke out.

VIII

Another type of alternator is the Alexanderson, evolved by E. W. F. Alexanderson[1] (Plate XXIII). This has a steel disc with 300 to 400 teeth on its edge, revolving at some 20,000 revolutions per minute between the poles of stationary magnets. No coils are carried on the moving parts, but, instead, the steel teeth deflect the stream of magnetic flux from the magnets and induce alternating currents in fixed coils.

---

[1] Now consulting engineer of the General Electric Company and chief engineer of the Radio Corporation of America.

Alexanderson alternators, which are said to be of the "inductor" type, give a frequency of 100,000 or over, and were first installed in the Radio Corporation's high-power station at New Brunswick, N.J. The first machine was of 50 kw., but it was soon apparent that a more powerful alternator would be necessary for continuous transatlantic communication under all conditions. A 200-kw. alternator was therefore produced, and this is claimed to be one of the most efficient and highly perfected radio-frequency alternators in existence. Two of these huge machines are installed at America's transoceanic station Radio Central, at Rocky Point, Long Island, as well as at other American stations. Alexanderson alternators are also in use at Carnarvon and elsewhere.

IX

To return, for a moment, to another difficulty encountered in early days of the Duddell and Poulsen arc experiments. Although the Poulsen improvement to Duddell's arc gave the necessary increased frequency, long-distance radio-telephony was still impossible, because of the difficulty in making the telephone transmitter carry a sufficiently powerful current for long-distance working.

Because of the necessity for a greater variation in the carrier wave, the current in radio-telephony is considerably greater than the current used in the line-telephone. It was found that the ordinary telephone transmitters would not stand up to any current that exceeded their ordinary supply.[1] They rapidly deteriorated, and the carbon granules became burnt out, even when an attempt to improve matters was made by surrounding the carbon with a water jacket for cooling purposes. By using a number of transmitters coupled together, however, a current of considerably greater power[2] was obtained. Even with such an arrangement, radio-telephony up to 200–300 miles only was possible, and at that distance the limit seemed to have been reached.

The invention of the Fleming valve and the subsequent introduction, by De Forest, of the third electrode, as already

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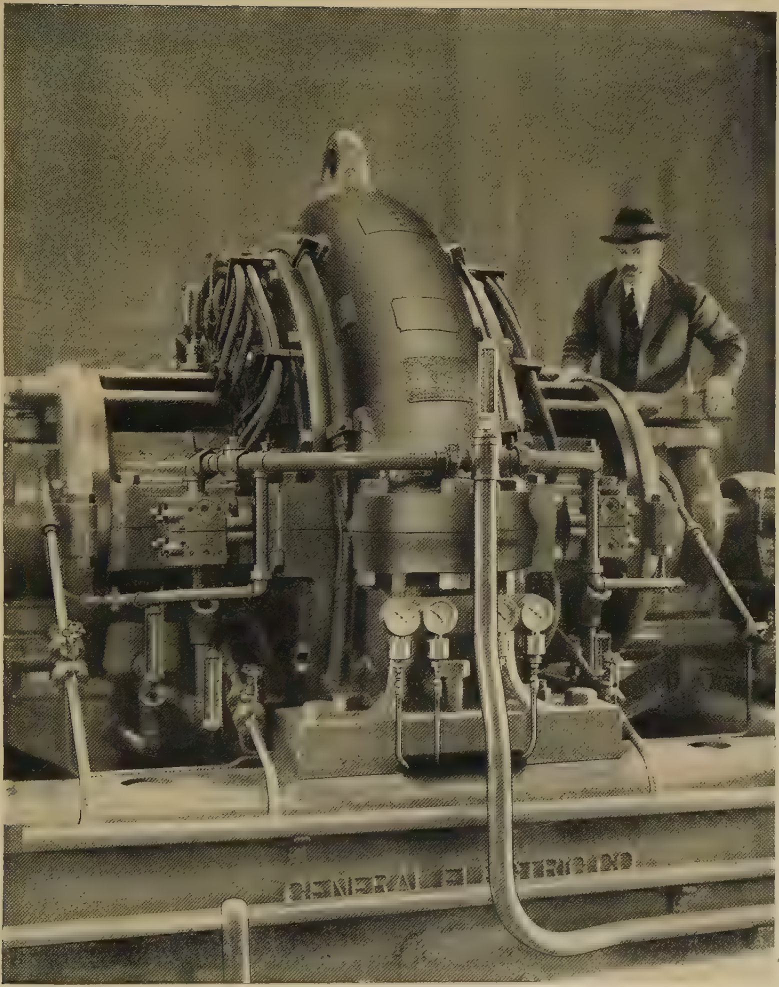
[1] About 20 to 30 milliamperes.

[2] About 15 amperes.



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E. F. W. ALEXANDERSON AND HIS HIGH-FREQUENCY ALTERNATOR

described, finally solved the problem of a satisfactory generator of high-frequency continuous oscillations.

In 1915 wireless telephone messages were successfully transmitted from Washington (U.S.A.) to Paris, and the Marconi Company provided the first demonstration of long-distance wireless telephony on a commercial scale when, in 1919, speech transmitted from Ireland was successfully received in Canada using only two transmitting valves and 2·5 kw. of energy. Wireless telephony is now an established branch of wireless, and its adoption for use in aircraft has greatly facilitated the progress of flying. The latest triumph in this direction was the establishment (in 1927) of direct connection between the telephone subscribers in London and New York (at a fee of £5 for three minutes' conversation)—a service that later was extended to Europe and any part of the United States.

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